THE RELATIONSHIP BETWEEN VOCABULARY AND GESTURE DEVELOPMENT IN EARLY CHILDHOOD AND INFANCY

by

KATHERINE HANNAH MUMFORD

A thesis submitted to the University of Birmingham for the degree of
DOCTOR OF PHILOSOPHY

School of Psychology,
University of Birmingham
September 2013

ABSTRACT

This thesis presents novel and original studies on the relationship between early vocabulary and gesture development. The thesis is split into two halves. First, the thesis addresses the issue of how seeing gestures can influence verb learning in 3-year-olds. Although previous studies have shown that gestures can aid word learning, the issue of *how* has not been addressed. This thesis is the first to demonstrate that gestures could help children to generalise novel verbs to specific referents within complex novel scenes.

Secondly, the thesis investigates the relationship between language and gesture in the left hemisphere, as indicated by the right-over-left preference for gesturing, in previously untested age groups. The thesis provides evidence that at the onset of referential communication a reorganisation occurs and this may be driven by receptive, rather than expressive, language development. Observational results showed that 3-year-olds tended to use their right hand when they had built multimodal representations of novel verbs. This thesis then describes the first study to manipulate gesture handedness in children, which suggests that encouraging right-handed gesturing has an advantage over left-handed gesturing in a language task. This thesis extends the current literature with studies that have important theoretical and practical implications.

For my parents and Matt,

I could not have done this without you!

ACKNOWLEDGEMENTS

I would like to thank all of the nurseries and families that took part in the studies that make up this thesis, without them this research would not have been possible. I would also like to the ESRC for funding this PhD.

I would also like to thank my supervisor Dr. Kita, for his patience and guidance throughout my PhD. I am also very grateful to all of my friends and family who have supported me through the last three years.

I would also like to thank Sandra Debreslioska and Emily Bright for their help in creating the stimuli used in Chapters 3 and 4 respectively. I would like to thank Elitsa Slavkova for her assistance with recruitment and testing for the study described in Chapter 6, and Federica Cavicchio for her reliability coding of the videos analysed in Chapter 6. Finally, I would like to thank Andrew Olson for his advice on mixed effects modelling.

CONTENTS

Part I- Verb Learning and Iconic Gestures

Part II- Right-handed Pointing and Vocabulary Development

LIST OF FIGURES

Chapter 3

Chapter 4

Chapter 6

Chapter 7

Chapter 8

LIST OF TABLES

Chapter 3

Chapter 4

Chapter 7

Chapter 8

LIST OF PAPERS

The following is a list of papers taken from this thesis:

Chapter 4

Mumford, K. H., & Kita, S. (in press). Children Use Gesture to Interpret Novel Verb Meanings. *Child Development*.

Chapter 6

Mumford, K. H., & Kita, S. (2013). Gesture handedness and language development in young infants. In S. Baiz, N. Goldman, & R. Hawke (Eds.), *Proceedings of the 37th Annual Boston University Conference on Language Development held in Boston, USA 2-4th November 2012* (pp 280-289). Somerville: Cascadilla Press.

Chapter 8

Mumford. K. H., & Kita, S. (under review). Encouraging right-handed pointing improves children's performance in a linguistic task.

CHAPTER 1

GENERAL INTRODUCTION

1.1

MOTIVATION

This thesis focuses on the links between gesture and vocabulary development in infancy and childhood and the issues surrounding this. Early vocabulary development is a very important area of research as vocabulary at 5 years has been shown to be a significant predictor of literacy, mental health and employment rates at 34 years (Law, Rush, Schoon & Parsons, 2009). Thus, understanding how gesture can influence early vocabulary may have important practical (as well as theoretical) implications. Many researchers now agree that there are strong links between language and gesture (McNeill, 1985). By understanding how these two interact during development and language acquisition we can inform and improve therapies and teaching strategies. For example, by understanding how typically developing children use gesture in language development, we can advise therapies for children who are not acquiring language typically. This thesis also explores the relationship between right-handed gesturing and vocabulary development in both infancy and early childhood.

This thesis, therefore, focuses on infants' very early pointing gestures and children's understanding and use of iconic gestures. Pointing gestures have been shown to predict children's later vocabulary (Iverson & Goldin-Meadow, 2005), while other research has shown that iconic gestures can influence children's learning of both first (e.g. McGregor, Rohlfing, Bean & Marschner, 2009) and second (Tellier, 2008) vocabulary acquisition. This thesis investigates whether they can use information from gesture during word learning, and how the relationship between language and gesture develops in infancy.

1.2

OVERVIEW OF THESIS

This thesis consists of two parts. The first part focuses on how seeing iconic gestures can influence verb learning in 3-year-olds. This part consists of a literature review and two experimental chapters. Each experimental chapter contains a brief outline of the study's goals and motivation followed by the study itself, written up in the form of an article.

Chapters 3 and 4 address the issue of how iconic gestures can guide children's semantic representations of novel words. Given that children must first be able to match the gestures, chapters 3 and 4 both contain a pre-test (which can be found in the appendices) in which children are asked to map gestures to a feature of the scene. The main experiments then address whether this information can bias children towards an interpretation of the novel word to fit the gesture. Chapter 3 addresses this question in the context of learning one novel word through several exemplars. Thus, there is a correct choice. Chapter 3 brings to light some methodological issues, which are addressed in Chapter 4. Chapter 4 asks whether children can use gestures when the meaning is ambiguous, as there is no correct answer.

Chapters 3 and 4 use the same paradigm to test word learning and this is now outlined briefly. Trials consisted of two phases: training and testing. Testing immediately follows training. In training, children are shown a video of an action of some sort, and hear a sentence, such as '*she's daxing it*'. Gesture manipulations occur at this stage. Then, children see two videos play side-by-side simultaneously. Each video keeps one feature from the original training video the same and changes another. Children are then asked to generalise the novel words, for example '*which one's daxing it?*' By observing which video children generalise the novel word to, we can infer which feature of the original video they had assigned the novel word to.

The second part of the thesis focuses on the relationship between right-handed pointing and vocabulary development. Chapter 5 is a review of this literature. This is followed by three experimental chapters, each with a brief introduction and then an article.

Chapter 6 investigates the co-development of language and gesture in the left hemisphere in 10 to 12-month-old infants. Although a different question, this issue fits in well with the rest of the thesis. As we have seen the links between gesture and language development in older children, it is important to understand how these links develop in infancy. In particular, this chapter focuses on the relationship between receptive language development and right-handed pointing.

Chapter 7 discusses the reanalysis of data obtained in Chapter 4 on verb learning, in light of the hand bias seen in Chapter 6.

Chapter 8 manipulates children's pointing handedness to investigate the nature of the relationship between gesture handedness and vocabulary development. Specifically, this chapter brings together the two core strands of the thesis: verb learning and handedness. It does this by investigating whether encouraging children to use their right hand during a verb learning task can improve acquisition.

Finally, although each experimental chapter contains its own discussion, the thesis contains a general discussion. This aims to pull all the previous chapters together (from both parts of the thesis), outline the important messages of the work and put them in the wider context of the literature. It also addresses the issue of future work.

1.3

A NOTE ON MIXED EFFECTS MODEL ANALYSIS

In the majority of studies described in this thesis the dependent variable was binary, that is, on any given trial, children could either be correct or incorrect. In these studies, generalised linear mixed effects models were used to analyse the data, using the statistical package R (R Core Team, 2013). These types of models show many advantages over the traditional Analysis of Variance (ANOVA) analysis (Jaeger, 2008). For example, as each trial is entered into the model, they avoid having to use the proportion of correct responses as the dependent variable, which would violate assumptions for t-tests and ANOVAs. Furthermore, by including each trial individually, they also maximise the information contained in the data, are more powerful and avoid errors in the output (Jaeger, 2008).

The models also allow random effects to be accounted for. Of particular importance for the current thesis, the models allow us to enter participants as a random variable; thus, the results can be generalised over participants. For the models used in the current thesis, random intercepts were calculated for participants. This reflects the variability across participants in their performance. When key comparisons were within participant, random slopes were also calculated for participants. This reflects the variability across participants as to the influence of a manipulation (i.e., some individuals may show a large influence and others may not show any influence). Furthermore, when a model included random intercepts by participants and random slopes by participants for a particular manipulation, the model also included the correlations between the two. These correlations reflect the relationship between these two. For example, it may be that a given participant performs very well overall (random intercept), and thus the influence of the manipulation for that participant (random slope) is reduced, while a participant who performs less well may be more influenced by the manipulation.

Although possible, the models used in this thesis do not include items as a random intercept or a random slope. This was because the design of the studies used such a small sample of items (between 4 and 7) and they were not designed to claim generalisability over items. This limited number of items was due to testing children, who have a limited attention capacity to deal with large numbers of trials. Although common in psycholinguistic studies to organise and analyse the data in terms of participants and items, in developmental studies, due to the limited number of trials, data is typically analysed in terms of participants only.

In order to understand whether particular effects were statistically significant predictors of the binary dependent variable, model comparisons were used. In these analyses a model with the effect of interest is compared to a model without the effect using a likelihood ratio test, to see whether that effect improved the model's fit significantly. Although this technique is often used for model selection when dealing with more complex data sets than described in the current thesis (e.g. many predictor variables), it can also be used to test the significance of particular factors of interest (See Burnham & Anderson, 2002).

Generalised linear mixed effects models were used whenever possible, but could not be used to compare performance to chance. For comparison to chance, one sample t-tests were used throughout. This is because generalised mixed effect models do not have anything equivalent to one-sample t-tests.

Finally, throughout the thesis statistical significance is treated as $p<.05$, while marginal significance is treated as $p<.1$. Thus, a non-significant result reflects when $p>.1$.

PART I

VERB LEARNING AND ICONIC GESTURES

'Suit the action to the word, the word to the action'

-*Shakespeare, Hamlet, Act 3, Scene 2*

CHAPTER 2

LITERATURE REVIEW I

2.1. THEORIES OF WORD LEARNING

Word learning is a huge challenge for young infants and children, who must learn to make sense of all of the linguistic input received. This section outlines theories of word learning. Section 2.2., will then focus on verb learning in particular.

Quine (1960) first outlined the problem children face when they hear a new word, in that it can refer to an almost infinite number of referents, from objects, to parts or features of objects, to actions and so on. A number of theories have now been developed which suggest how children might overcome this problem.

It is clear that language learning changes as the speaker becomes more competent with the language. Golinkoff and colleagues (1994) outline two tiers of competencies which infants and children must acquire in order to be able to learn a language. On the first tier are the three following principles: reference (words, or signs, can be used to refer to concepts in the real world), extendibility (words, or signs, can be generalised to other exemplars) and object (words refer to whole objects, this is discussed below). When children have only acquired the tier one principles, language learning is slow and arduous; these skills only allow children to understand the basic principles behind using words appropriately, and words must be learned individually and after many repetitions. The second tier consists of the following three principles: categorical scope (whereby children can generalise words based on whether objects are the same kind, rather than solely based on perceptual features), the nameless category principle (N_3C- also known as mutual exclusivity and discussed below) and conventionality (all speakers of the same language use the same word forms for the same concepts). This tier of competencies allows children to learn language at a much faster rate, using their previously acquired knowledge to scaffold their learning. There are, however, many more strategies that children can use to learn words.

The idea of natural constraints or principles has also been suggested as a possible solution to Quine's (1960) problem (e.g. Golinkoff, Mervis & Hirsh-Pasek, 1994). This idea suggests that infants have certain biases to limit and guide what words may refer to (e.g. Golinkoff et al., 1994). For example, Markman and Wachtel (1988) describe when children encounter a novel object and hear a novel word, they are most likely to map that word to the whole object, rather than a part of that object, a property it has or something that it does. Similarly, infants in their second year have been shown to have a strong tendency to generalise novel nouns based on shape (e.g. Graham & Poulin-Dubois, 1999).

Mutual exclusivity is the concept that at each level of categorisation each object has only one name, thus if you know the name for an object and hear a novel word, that word cannot refer to the object at the same level (Markman & Wachtel, 1988)[1]. Markman and Wachtel (1988) found that children could use this to learn meanings of novel words. They found that if children knew the label for the whole object, they assigned a novel label to part of that object, whereas if the whole object was novel, children applied the novel label to the entire object. Indeed, these principles can be strong enough to ignore other information. For example, Hansen and Markman (2009) found that if children were presented with a novel

[1] Note, there are several constraints that are similar, but not identical to the mutual exclusivity constraint, such as the contrastive principle (Clark, 1987) and the N_3C (Golinkoff et al., 1994), which are not discussed in detail in this thesis.

object and a specific part was highlighted through gesture, children still mapped a novel word to the whole object.

Children have been shown to use context to map words to referents, for example, '*fast mapping*'. Fast mapping is when children map a novel word to a novel object surrounded by familiar objects. For example, if children see a set of familiar objects (or features such as colour or shape) and one unfamiliar and hear a novel word, they will frequently map the word to the unfamiliar object (or feature) (e.g. Heibeck & Markman, 1987). This phenomenon appears to be specific to linguistic tasks, such that 2-year-olds will not assume a novel fact is about one novel object after they have heard another fact about a different object (Scofield & Behrend, 2007).

Saliency has been shown to influence very early word learning. For example, 10-month-olds have been found to map novel nouns onto the most salient object present (Pruden, Hirsh-Pasek, Golinkoff & Hennon, 2006). It is possible that a gesture depicting a particular feature may make that feature more salient and so easier for children to map words to. This is an idea that is explored in the first part of this thesis.

Related to this is the issue of novelty when learning novel words. Research has shown that young children find verb learning more difficult if agents are unfamiliar to them (Kersten & Smith, 2002). They argued that when agents are novel, children found them distracting, making it more difficult for them to learn the referent of the novel verbs (the actions). Similarly, Maguire and colleagues (2008) found that 2-year-olds were more likely to extend a novel verb correctly if they had seen one video repeated four times, compared with seeing four different actors performing the action. It is thought that seeing different actors was distracting to the children and inhibited learning of the verb (Maguire, Hirsh-Pasek, Golinkoff

& Brandone, 2008). Thus, it appears that familiarity of the objects and actors may be critical in enabling children to learn words effectively.

In contrast to work showing familiarity is crucial for word learning, other researchers have argued that seeing different exemplars is crucial when learning words. At the structural level Gómez (2002) found that adults and 18-month-old infants were able to learn nonadjacent sounds in three-syllable words when the middle syllable was very variable. Further, using transcripts of child-mother interactions, Sandhofer and colleagues (2000) found that while mothers tended to use lots of different nouns with similar meanings, they preferred to use a small number of verbs in various contexts. This suggests, that for verbs at least, having different exemplars may be useful (or at least parents act as if this is useful!). Other research has suggested that children require multiple, rich exemplars in order to build an understanding of words at the super-ordinate level (e.g. '*animal*' '*food*') (Liu, Golinkoff & Sak, 2001). Similarly, unusual exemplars (e.g. dodo as an example of a bird) are helpful for children to organise categories (Gelman & Coley, 1990), suggesting that a range of typical and atypical exemplars can be beneficial for word learning at different levels. Finally, it has been argued that children are able to learn verbs by comparing between exemplars to eliminate alternative possibilities leaving only the true meaning of the verb (See Gleitman, 1990, for a discussion of this debate).

Research has also shown that prosody can guide children's attention when learning novel words. For example, Herold and colleagues (2011) taught 4- and 5-year-olds new words using prosody as the only cue (e.g. slow, deep voice for a large object and high, fast voice for a smaller object). The results showed that children were able to use pitch and intonation when learning new words. The results showed that this ability developed with age, however, even 4-year-olds were able to use prosody if they were given explicit training to pay attention to it

(Herold, Nygaard, Chicos & Namy, 2011). This work is similar to research on sound symbolism and word learning discussed below (e.g. Imai, Kita, Nagumo & Okada, 2008; Kantartzis, Imai & Kita, 2011), such that there is a non-arbitrary relationship between sound and meaning that can guide word learning.

Use of existing language

After a certain amount of language learning has already occurred, children are able to use their knowledge of their language to guide their word learning. Infants as young as 12 months have been shown to use their understanding of legal and illegal phonological word forms to guide their word learning, such that infants only mapped a novel word to an object if the word form was phonotactically legal in their native language (MacKenzie, Curtin & Graham, 2012). Further, research has also found that infants' ability to recognise legal and illegal word forms correlates with their vocabulary development (Estes, Edwards & Saffran, 2011).

Children are able to use knowledge of the syntactic structure of their language to map novel words (e.g. Landau & Gleitman, 1985) as well as the statistical biases towards certain types of verbs compared to others (e.g. Maguire, Hirsh-Pasek, Golinkoff, Imai, Haryu, Vanegas et al., 2010). This will be discussed in more detail in Section 2.2.

Finally, Rohlfing (2006) found that children benefited from using contrast. For example, in one study 23-month-olds were taught the word '*under*'. Some infants were taught the word on its own and others were taught it being contrasted with '*on*' or '*in*' (which are typically learned earlier than '*under*'). The results showed that infants who heard the contrast performed better when generalising '*under*' to a novel context. This shows that having previous experience of a language can benefit later learning.

Social-pragmatic view point

There is now a growing literature that suggests social interactions are a very important feature when considering children's ability to learn words. This suggests that Quine's problem was too narrowly focused as it discarded any support children get for word learning from others around them. Nelson (1988) argues that Quine's (1960) problem should actually be reversed, such that the problem is adults trying to guess and correctly label what infants are attending to, so that they can label what they are interested in. In either case, it appears that learning language is necessarily social, and children quickly learn to use socio-pragmatic cues to help them to understand the meaning of words.

In particular, Tomasello (2008) highlights the role of common ground or joint attention in word learning. For example, in a study by Akhtar and colleagues (1996) 24-month-olds played with three toys with adults, then one adult left and another new toy was added, for the child and remaining adult to play with. When the original adult returned, they became excited and produced a novel word. Despite all the toys being familiar to the children, they understood that the new word referred to the toy which was novel to the adult (Akhtar, Carpenter & Tomasello, 1996). This demonstrates how children's word learning can be guided by pragmatic cues and common ground.

Infants and children appear to be able to use social cues in communication from early on in their development. It has been argued that infants as young as 3 months are able to shift their attention to follow eye gaze (Hood, Willen & Driver, 1998) and infants as young as 4.5 months can shift their attention to a dynamic pointing gesture (Rohlfing, Longo & Bertenthal, 2012). It has also been suggested that the use of eye gaze is a strong ostensive cue for infants that communication is being directed towards them (Csibra & Gergely, 2009), thus they can gauge when to pay attention to speech. Parise and colleagues (2011) found that 4- to 5-month-old infants were surprised (as measured by an N400 effect) when they saw a gaze directly at them, but heard backwards speech. This suggests that the infants were expecting the message to be targeted to them and so were surprised when this message was unfamiliar (Parise, Handl, Palumbo & Friederici, 2011).

As well as using eye gaze to understand a message is targeted at them, infants are also able to use eye gaze to correctly understand the referent of novel words. Baldwin (1991, 1993) found that by 18 months, infants could use adults' eye gaze to correctly map a novel word to what the adult was focused on rather than what the infant was attending to. Further, at 24 months, eye gaze could be used to facilitate learning through the mutual exclusivity principle if the two were congruent, but eye gaze could not override this principle if they were mismatching (Graham, Nilsen, Collins & Olineck, 2010).

Perhaps unsurprisingly, research has shown that 30-month-olds can use pointing gestures to infer the target of ambiguous object labels (e.g. Booth, McGregor & Rohlfing, 2008). It appears, however, that these cues can be very strong and are able to override linguistic information. For example, Grassmann and Tomasello (2010) tested children's fast mapping with one known and one unknown object. If the experimenter pointed to a familiar object and requested an object using a novel label or if they pointed at an unknown object and requested an object with a known label, 2- and 4-year-olds nearly always followed the point and ignored the speech (Grassmann & Tomasello, 2010). However, Jaswal and Hansen (2006) found the opposite pattern, such that children followed the mutual exclusivity response and ignored pointing or eye gaze. This is consistent with Hansen and Markman's (2009) work on the whole object bias, where children mapped a novel word to a whole object even if a specific part was highlighted through gestures. In a follow up study, however, Jaswal (2010) found that if pointing and eye gaze were combined then children followed these cues rather than linguistic ones. This demonstrates how powerful socio-pragmatic cues can be.

Finally, it has been shown that by 13 months, infants will look to an adult to obtain further cues when they are unsure about the referential target, thus they are aware about when they need additional referential support (Vaish, Demir & Baldwin, 2011). At around the same age, infants understand the importance of the speaker's intention to label an object. For example, infants do not map any novel word to any novel object regardless of the context (Baldwin, Markman, Bill, Desjardins, Irwin & Tidball, 1996).

Infants' and children's use of gesture to understand word meaning is an area of research which is particularly relevant to the current thesis. This will be discussed in detail in section 2.3.

Research has also shown that children prefer to learn from a speaker who is knowledgeable (e.g. Koenig & Harris, 2005; Sabbagh & Baldwin, 2001). If children have seen two speakers, one labelling familiar nouns correctly and one labelling them incorrectly, children will choose to learn from the former one, rather than the later (Koenig & Harris, 2005) This is true for learning linguistic and non-linguistic information (Koenig & Harris, 2005). Children also judge speakers based on their apparent confidence in what they are communicating, as demonstrated by clear, direct statements or verbal uncertainty, and learn better from informed speakers compared with ignorant ones, even if sufficient referential cues (e.g. pointing) are available (Sabbagh & Baldwin, 2001). Children are also able to judge who is the most reliable speaker based on the non-verbal cues (nodding, smiling vs. head shaking, frowning) of bystanders who are not directly involved in the conversation (Fusaro & Harris, 2008). This shows how non-verbal cues, possibly including gestures, may be a way for children to rate the reliability of a speaker. Although this is not the key focus of this thesis, it is important to note that children may be able to use gestures in a range of ways in a word learning context, not only to understand what is being referred to, but the speaker's own trustworthiness.

Emergenist coalition model

Hollich and colleagues (2000) proposed the emergenist coalition model of word learning which suggests that children use many different cues, and vary which one they rely on more on as different abilities and principles develop. This is consistent with Golinkoff and colleagues' (1994) use of a two tiered system of competencies. Hollich and colleagues (2000) suggest that firstly infants rely on perceptual cues, then social ones and finally linguistic ones. This idea is consistent with previous literature on individual cues used, but draws them all together and suggests they may interact with each other, rather than working in isolation. For example, it may be that social cues make a particular referent more salient to the infant, who then draws on his or her saliency bias to select that as the referent for a novel word.

Grounding language in human experience

Many researchers have argued in support of a link between language and action (e.g. Glenberg & Gallese, 2012). For example, adults can process sentences better if a simultaneously produced action is congruent with the movement in the sentence (Glenberg & Kaschak 2002; Zwaan & Taylor, 2006).

Embodied learning, learning through hands

Actions made upon novel objects, when learning a novel label, have been shown to influence children's understanding of what novel labels refer to (e.g. Kobayashi, 1997, 1998;

O'Neill, Topolovec & Stern-Cavalcante, 2002). Kobayashi (1997) taught 2-year-old children labels for novel objects. Teaching was either accompanied with an action that highlighted an object's shape (e.g. rolling a glass egg), or its material (e.g. looking through the glass egg). Children were then asked whether the novel label could be used with an object with the same shape or the same material. If children saw material actions they were more likely to believe that the label referred to the material, and the opposite was found if children saw the shape actions. This shows that children can use information from peoples' actions/ hands to focus on particular features of an object.

In a further study, Kobayashi (1998) investigated 2-year-old children's abilities to learn labels for parts of objects. Kobayashi (1998) found that if children saw an action on part of an unfamiliar object (e.g. tightening a nut), then they were able to overcome their whole object bias and understand that the novel label referred to the nut alone. In contrast, if children simply saw a pointing gesture towards the nut, they believed the novel label referred to the entire object. This demonstrates that social cues can be used to help children overcome their natural constraints and biases when learning new words. It is also interesting as it suggests that children can use actions made upon objects to overcome the whole object bias and select a part of an object as the referent, when they cannot use outlining gestures to do the same (Hansen & Markman, 2009).

O'Neill and colleagues (2002) extended this idea by teaching 2- and 3-year-old children unfamiliar adjectives with novel objects (e.g. '*look, it's a lumpy cat!*'). Children were then asked to select another lumpy toy to give to the experimenter. Some children were taught the novel adjectives while the experimenter pointed at the toy. For the other children, the experimenter used an action on the toy (termed '*descriptive gesture*' by the authors), which highlighted the relevant feature (e.g. for the word '*lumpy*' the experimenter felt the beans within the toy between their finger and thumb). Children who saw actions were more likely to select the correct toy at test than children who saw pointing gestures. In particular, seeing an action performed on the object had a large effect on children's understanding of the adjectives if the adjective referred to an invisible property (e.g. lumpy). In contrast, seeing an action performed on the object had less effect on children's understanding if the property being referred to was visible (e.g. fleecy).

O'Neill and colleagues (2002) also found an association between children performing the action on the test toys and then selecting the correct toy, particularly in the group who had seen the actions demonstrated to them, as opposed to the group who had seen a pointing gesture. However, it was not simply the case that children who had seen the actions demonstrated were aware of the referent features of the toys, since children who saw the actions, and those who saw pointing gestures produced the actions themselves. In contrast, it seems that only children who had seen the action demonstrated understood that this feature was the referent. It appeared that if children saw an action demonstrated, and then imitated it themselves they were most likely to map the word to the correct referent. The study showed that children appear to be able to use information contained in the actions of others to focus in on the intended referent of novel adjectives.

2.2

VERB LEARNING IN CHILDHOOD

It has been noted that cross-culturally children demonstrate a '*noun bias*' in language acquisition, such that nouns are acquired earlier than other word classes such as verbs and adjectives (e.g. Gentner, 1982; Bornstein, Cote, Maital, Painter, Park, Pascual et al., 2004). One argument for this, explained by Gentner (1982), is the natural partitions hypothesis, which suggests that referents for nouns are inherently more conceptually simple than referents for other word classes. Nouns tend to refer to objects, people, animals, places (as well as more abstract concepts), while verbs refer to actions, occurrences or states of existence. Further, many verbs can involve the interaction of multiple agents and objects. (Note, that there is a linguistic relativity debate here, such that language itself has set up the distinctions in the world, making some things more complicated than others (e.g. through morphology, syntax) (Gentner, 1982)). It does appear then, that verbs are more difficult to acquire than other syntactic categories, this section will address the review the literature on verb learning.

Although there are many different types of verbs, this thesis focuses on manner and change-of-state verbs. Manner verbs are those that refer to how an action is performed while for change-of-state verbs, manner is irrelevant but what is critical is the state of the scene at the end.

Teaching novel verbs

When testing children's abilities to learn novel verbs, researchers typically teach a verb in a specific context and then ask children to generalise that verb to contexts in which one feature has been changed. The logic is that if children are unwilling to generalise to the new context then the changed feature was important in their representation of the verb. If children are willing to generalise across the changed feature then that feature is not considered important in the children's representation of the verb's meaning.

It is important to note that the methodology used to investigate verb use may be important, since verbs typically refer to dynamic situations. Some studies using pictures, which depict a scene before and after an event (so the child must infer what has happened between the two scenes), have found poor performance in 5-year-old children (e.g. Gropen, Pinker, Hollander, & Goldberg, 1991). It may be that children simply failed to understand the event itself and, as a result, their verb usage has been underestimated. In Chapters 3, 4, 7 and 8, when children were taught novel verbs, video clips were used, to ensure that children understood the entire sequence of events. Research has shown that 30- to 35-month-olds can learn verbs from videos when supported by social interaction and 36- to 42-month-old can learn from videos alone (Roseberry, Hirsh-Pasek, Parish-Morris & Golinkoff, 2009). This was, therefore, considered an appropriate method of introducing children to the referents of novel verbs.

Learning and generalising novel manner verbs

When learning novel verbs, children often believe that the actors, as well as the actions are important to the meaning of the new word. For example, Forbes and Farrar (1993) found that, overall, children were less likely to generalise a novel manner verb if the causative agent was changed compared to a change in manner. Kersten and Smith (2002) showed 3-year-old children clips of novel insects moving and taught them either a novel noun (type of insect) or a novel verb (the movement of the insect). Children were then shown four types of videos: identical, same insect but different action, different insect but the same action and different action and insect. Children were asked yes/ no questions in order to determine their understanding of the novel words (e.g. '*is this a* (NOVEL NOUN)*?*' in the noun condition or '*Is he* (NOVEL VERB)-*ing?*' in the verb condition). Children who were taught a noun generalised the novel noun to other videos of the same insect whether the action was the same or different. In contrast, they rarely generalised the novel noun to a novel insect, even if the action was the same. This shows that when they were learning a novel noun, the children correctly focused on the insect. This pattern was also found in adult participants.

Children, who were taught a novel verb, agreed that when the action and insect remained the same the verb could be applied. However, they were equally likely to say the novel verb could be applied when the insect changed (same action) as when the action changed (with the same insect). This shows that when children learn a novel verb, they believe both the agent (the insect) and the manner are important features (Kersten & Smith, 2002).

In a final experiment, Kersten and Smith (2002) demonstrated that if children were familiar with the agents (using vans instead of insects) when they learned novel verbs, they were much better at focusing on the action of the agents rather than the agents themselves.

The authors suggest that verbs may be difficult to learn, as they can vary much more depending on context (Kersten & Smith, 2002), for example, the verb '*to throw*' can be used to describe the action of different people, who can throw different types of objects, using different actions (one hands, two hands, under over arm) and can even be used metaphorically (e.g. throwing away an opportunity). In contrast, although nouns may change in design, or colour, they remain relatively stable across contexts (e.g. a ball in one situation will be fairly similar to a ball in a completely different context). In order to understand the meaning of a novel verb, Kersten and Smith (2002) argue that you must first understand the context and know what is relevant. Therefore, when unfamiliar agents are used children also focus on them. This account can also explain why children typically learn nouns before they learn verbs (Bornstein et al., 2004), since to learn verbs they must be familiar with a range of contexts that the verb can be applied to, whereas the referents of nouns do not vary much between contexts.

It may be that when scenes are unfamiliar, children have a bias to assign words to the entire scene. For example, as discussed in section 2.1., children typically demonstrate a whole object bias (e.g. Markman & Wachtel, 1988) such that when they encounter a new object they have a tendency to believe that a novel word refers to the whole object, rather than the parts. Only when the word for the whole object is known can a novel word be assigned to a part of the object. Similarly, Kersten and Smith (2002) found that when children encounter a novel scene, with novel characters, they believe a novel verb refers to the entire scene. In contrast when the characters are familiar, children were more willing to accept that the novel word could refer to a part of the scene (the action).

Imai and colleagues (2005) found that children typically believe that the object-action interaction is also an important feature of a novel verb's meaning. They taught 3- and 5-year-olds either novel verbs or novel nouns, using video clips of an actor using an object in a particular way. Children were then shown two further videos, in one the action was changed and in the other the object was different (the actor was the same in all conditions). Children were asked which video the novel word could be applied to. All the children were able to correctly generalise the novel noun to the video with the same object. However, only 5-year-olds could generalise the novel verb to a different object.

It may be, however, that children's abilities have been underestimated due to methodology. For example, Waxman and colleagues (2009) used a looking paradigm with 24-

month-olds and found that they were able to map a novel verb onto an action. Thus, as children can learn verbs at this age, a more suitable question to ask is: what conditions are best for verb learning?

It has also been shown that 3-year-olds are able to identify referents of familiar manner verbs, such as '*to walk*' when the referents are shown as moving dots (Golinkoff, Chung, Hirsh-Pasek, Liu, Bertenthal, Brand et al., 2002). This shows that children's representation of novel verbs include some abstract representation of the action alone, independent of any actors.

Learning and generalising novel change-of-state verbs

Children appear to understand that end states are important. Children often have a goal bias, as opposed to source bias, when they are watching a scene, such that they are more likely to encode an end point of an agent, compared to a starting point (Papafragou, 2010). Further, Behrend (1990) taught children novel verbs and found that, overall, children were most reluctant to generalise a novel verb when the end result changes and this effect increased with age. The results indicated that the children believed that the result was important to the verb's meaning (Behrend, 1990).

Other research, however, has found that children show a manner bias when learning novel verbs. In a similar study to Brehend's (1990), Forbes and Farrar (1995) taught 3-year-olds novel verbs, through various types of training, and then asked them to generalise the verbs to new videos where one feature of the scene (result, manner, instrument or agent) had changed. Overall, children were most reluctant to generalise a verb when the manner had been changed. In addition, the type of training children received had a significant impact on their understanding of the novel verbs. When the result was different in each of the training exemplars, 3-year-olds were willing to generalise the novel verb to situations where the result differed again; children understood that the result was not critical. In contrast, when the manner was different in each of the training exemplars, children still believed that the manner was important (Forbes & Farrar, 1995). This indicates that young children may have a strong tendency to assume that the manner is important in new verbs' meanings.

The study by Forbes and Farrar (1995) highlights the importance of the type of training children receive on their choices in generalising novel verbs. In Behrend's study (1990) children were shown one single exemplar before testing, and demonstrated a result bias. This is most similar to Forbes and Farrar's (1995) condition in which children viewed a single exemplar three times. This condition also found a strong tendency to not generalise if the result changed. Thus, the two studies are compatible, although Forbes and Farrar's (1995) study emphasises the large impact training can have on verb generalisation. For most of the studies in the current thesis, when verbs are taught to children, they are done so by showing a single exemplar shown twice, which may lead to a result bias similarly to Behrend's (1990) and Forbes and Farrar's (1995).

Older children have been shown to demonstrate a manner bias when generalising familiar change-of-state verbs. Children often believe that how a change occurs, and not the result of that change, is critical to a verb's meaning (Gentner, 1978; Gropen et al., 1991). For example, Gropen and colleagues (1991) showed children picture strips, depicting familiar change-of-state verbs, such as '*to fill*'. The strips either depicted a manner but no change of state (e.g. a woman pouring, but spilling, water so a glass remained empty) or no direct action but a change of state (e.g. a tap dripping and a glass becoming full). Participants were then asked which one was pouring / filling. Again, children did well when applying manner verbs (such as pouring), but did poorly when applying change-of-state verbs (such as filling).

Children incorrectly believed that the manner was more important than the change of state, such that pouring was a critical feature of the verb '*to fill*', and the change in fullness of the glass was not. In a similar study, Gentner (1978) found that children were able to use manner verbs such as '*to stir*' by 5 to 7 years old but failed to apply the change of state verb '*to mix*' appropriately until 7 to 9 years old. However, due to methodological issues described above we should be cautious when drawing firm conclusions from these studies.

Strategies for learning the meaning of novel verbs

After reviewing the literature on the patterns children display when learning and generalising new verbs, we will now consider some of the strategies that children have been shown to use to build a representation of the meaning of novel verbs and that are relevant to the studies in the dissertation.

Sound symbolism

Research has shown that children can use sound symbolism to learn the meaning of novel verbs. Sound symbolism is the inherent link between a word's meaning and form, for example, when shown a rounded shape and an angular one and given two labels, adults usually assign the label '*maluma*' to the rounded shape and the label '*takete*' to the angular one (Köhler, 1947). As such, sound symbolism is similar to iconic gestures, which also have a link between form and meaning. Although sound symbolic words, or ideophones, are relatively rare in English, other languages (such as Japanese), have a large amount of sound symbolic words (See Nuckolls, 1999, for a review). Imai and colleagues (2008) found that when a novel verb sound symbolically matched the referent action, children found it easier to identify the action as the referent, and not the actor, than when the verb did not sound symbolically match the action (for English children see Kantartzis, Imai & Kita, 2011).

Sound symbolism and iconic gesture are similar in that they both exploit non-arbitrary relationships between symbols and referents. Further, research has shown that young children are more likely to use iconic gestures when also using sound symbolic words compared to when they used non sound symbolic words (Kita, Özyürek, Allen & Ishizuka, 2010). Chapters 3 and 4 will investigate whether iconic gestures can also guide verb learning in children.

Syntactic bootstrapping

Landau and Gleitman (1985) proposed the syntactic bootstrapping hypothesis, whereby children are able to use knowledge of sentence structure and verb meaning to map the meaning of a novel verb. This hypothesis was tested by Naigles (1990), who found that 2-year-olds were able to use syntax to learn the meaning of novel verbs (e.g. children who heard a transitive structure believed the verb was causal and those who heard an intransitive structure believed the verb was non-causal). Consistent with this theory, Gertner and colleagues (2006) have found that young children can also use word order in transitive sentences to map the meaning of novel verbs, e.g. '*the bunny's gorping the duck*' vs. '*the duck's gorping the bunny*'.

Surrounding context

Children are able to use the context in which events occur to narrow down the meaning of novel verbs. For example, children are able to use adverbial modifications to sentences, combined with knowledge of events, to guide their representation of a verb's meaning. Wittek (2002) found that using the adverb '*again*' could alter children's interpretation of the meaning of a novel verb. The word '*again*' can be used to describe verbs in two ways. First, it can be used with manner verbs to describe the repetition of an action, for example '*he dropped his phone again*'. Secondly, it can be used with change-of-state verbs to describe the return of something to a previous state, for example '*he broke his phone again*'. In change-of-state verbs, the action that brings about the change is not important, but the end state is. If the listener is aware of how the phone initially became broken and knows that the second action is different, then the only valid interpretation of the verb '*to break*' is as a change-of-state verb. Wittek (2002) tested this idea by teaching 4- and 5-year-olds a novel verb using videos, in which someone returned something to its original state by using a different manner. Some children heard the adverb '*again*' in the training sentence, whilst others did not. Children who heard '*again*' were more likely to choose a change-of-state interpretation compared to children who did not hear the adverb '*again*'. This shows that small adverbial modifications can act as a cue for children to select a change-of-state interpretation for a novel verb.

Children are also able to use the surrounding context to understand the meaning of new words, including verbs. For example, Golinkoff and colleagues (1996) showed 34-month-olds four pictures of characters performing actions, three were familiar (e.g. eating, reading) and one was unfamiliar (e.g. doing the splits). When children were asked about a novel verb ('*where's daxing?*') they were able to fast map the verb to the unfamiliar action. Further, the children showed some ability of using this newly learned word to rule out a possible interpretation of a second novel verbs (mapping to a second novel action). This demonstrates that children are able to combine their previous knowledge (familiar actions and verbs) and their understanding about the current contexts in order to successfully map the meaning of novel verbs to novel actions.

How children generalise verbs

Categorical scope principle

Golinkoff and colleagues (1994, 1995a) have proposed the categorical scope principle, which states that children will extend novel words to similar exemplars in the same taxonomic category. They have also argued that this same principle can be used to extend novel verbs (Golinkoff, Hirsh-Pasek, Mervis, Frawley & Parillo, 1995b). They suggest that children can extend verbs on the basis of action, that is to other actions that differ in who is performing them and minor differences in action execution (Golinkoff et al., 1995b). For example, after 34-month-old children had fast mapped verbs, they could generalise these to new actors (Golinkoff, Jacquet, Hirsh-Pasek & Nandakumar, 1996). However, this principle does not seem to account for the difficulties children demonstrate when generalising novel verbs (e.g. their belief that the actor is important). It may be that Golinkoff and colleagues' (1996) use of pictures rather than videos as exemplars of novel verbs, simplified the problem for children, and so they were able to generalise to novel actors, whereas in the real world, this remains challenging for them.

The role of verb type in verb extension

Research has found that children find generalisations of some types of verbs easier to understand than others. Seston and colleagues (2009) investigated extensions of instrument specific verbs, for example, '*he vacuumed the milk with his mouth*', compared to open verbs, which are not linked to a particular object (e.g. '*to chop*'). The results showed that 6- to 8-year-old children could interpret novel extensions of instrument specific verbs more easily than open verbs (Seston, Golinkoff, Ma & Hirsh-Pasek, 2009). They argue this may be because instrument specific verbs are easier to imagine or that referent actions for instrument specific verbs look similar, for example vacuuming the stairs is similar to vacuuming the hall. In contrast the referent action associated with open verbs may look less similar (e.g. chopping wood vs. chopping vegetables). The authors suggest that this may make specific instrument verbs easier to learn the meaning of, and also extend. As previously discussed, children appear to be better at extracting the meaning of verbs better when they see the same exemplar repeated rather than several different exemplars (Maguire, Hirsh-Pasek, Golinkoff & Brandone, 2008). In a similar way, the exemplars for instrument specific verbs may be more similar to each other (since they are used in less varied contexts), compared to open verbs, which may vary much more between contexts (e.g. there are many differences between chopping wood and chopping vegetables). This may make it more difficult for children to focus on the essential features of the scene to learn the verb, and ultimately to generalise the verb to novel situations.

This section has highlighted some of the biases and difficulties children face when learning to generalise new verbs appropriately. The next section will investigate the relationships between language and gesture so that we might investigate how gestures may also help children to learn the meaning of novel verbs and extend them to new exemplars.

2.3

GESTURES

Types of gestures

This thesis primarily focuses on gestures (or gesticulations) that occur with speech, but it is worth considering where these fit into a range of manual hand actions. This is known as Kendon's Continuum, in honour of Adam Kendon who first described the phenomenon (Kendon, 1988; McNeill, 1992). Actions are ordered by the strength of their relationship to speech in the following way (starting with the strongest association): gesticulations (gestures), pantomimes, emblems and signs. Gestures are those that often accompany speech and are created along with speech. The form of the gesture is flexible and often is ambiguous without the co-occurring speech. Pantomimes, however, can occur without speech and show slightly more structure, such that they can be combined to tell a story, unlike gestures. Pantomimes are still, however, relatively flexible in form and the hands can be used idiosyncratically to represent different features of objects or actions. Emblems are culturally specific actions, such as '*thumbs up*' to mean good, in English cultures, or the '*OK*' sign. As they are culturally decided, they can be used within that culture in the absence of speech and the message is clear to the receiver. Last on Kendon's Continuum are sign languages in which the hands are used to create a complete linguistic system, with all of the linguistic properties of a spoken language.

This thesis will focus on gestures, which can in themselves be broken down to different subcategories. McNeill (1992) describes fives main subtypes of gestures: iconic, metaphoric, beat, cohesive and deictic. Iconic gestures are those that, either in hand shape or movement, have a close semantic relationship with the co-occurring speech. These are used to depict concrete actions or objects in the world, based on similarity. Iconic gestures contain information related to the referent, for example, using hands to hold an imagined object, gives information about the size, and possibly about the shape of the object. Similarly, tracing an arc with an index finger can depict the trajectory of an agent in the verb '*to jump*'. Some of the information contained in gesture is not always simultaneously available in the concurrent speech, for example, when gesturing while saying '*he threw the ball*', gesture can clarify how the ball was thrown (e.g. with two arm or one, under or over arm etc.). Metaphoric gestures, in contrast, are when the hands are used to depict a more abstract concept, by providing a concrete hand form, for example, when comparing two sides of a debate, the hands can be used as if trying to balance the pieces of information. Beat gestures are simple up-and-down hand movements that are associated to the speech rhythmically. Although beat gestures show no obvious information in their form, they provide important information on the discourse, for example by allowing the speaker to emphasise key words or phrases. Cohesive gestures can be iconic, metaphoric or beat like in form, but serve the purpose of linking different aspects of the speech together, for example repeating a gesture in a similar location to previously to tie the concepts together. The final category is deictic gestures, such as pointing. These can be used to indicate something concrete in the surrounding environment or can be used to refer to an abstract concept or missing item.

Chapters 3 and 4 in this thesis investigate the role of seeing iconic gestures during word learning, while Chapters 6, 7 and 8 will focus on the production of pointing gestures.

Development of pointing gestures

Pointing is found cross culturally (Liszkowski, Brown, Callaghan, Takada & de Vos, 2012), and emerges at around 11 months (Butterworth & Morissette, 1996). Pointing to objects is an important milestone in infants' communicative abilities and is associated with other social abilities at a younger age such as eye gaze (Matthews, Behne, Lieven & Tomasello, 2012). Bates and colleagues (1975) described different two types of pointing gestures: imperatives, where the point reflects the individual's desire to obtain something, such as an object, and declaratives, where the point reflects the individual's desire to share knowledge about something with another person. Liszkowski and colleagues (2006) note a third type of pointing termed '*informative*', where the infant wants to share information with something else that might be useful. Although the evidence regarding the emergence of pointing gestures is mixed, overall it appears that declarative and imperative gestures emerge at roughly the same age (Carpenter, Nagell & Tomasello, 1998). It appears, however, declarative informative gestures appear to increase in frequency with age (Cochet & Vauclair, 2010). Chapter 6 of this thesis investigates handedness of imperative points and its relationship to language development.

Expressive language development and gesture

The links between gesture and language appear very early in development. Between 4 and 12 months, the proportion of hand movements (including reaching, pre-points and points) which are accompanied by a vocalisation increases (Blake, O'Rourke & Borzellino, 1994). Similarly, Iverson and Fagan (2004) found that infants' vocalisations were more coordinated with manual (arms or hands) movements compared with non-manual (legs, head, or torso) movements. These may be demonstrating the foundation of the gesture-language system.

Gestures have been shown to predict language development in toddlers in a number of ways. Firstly, gestures have been shown to predict later vocabulary development. In a longitudinal study, Iverson and Goldin-Meadow (2005) observed that children pointed to an object around three months prior to the acquisition of the verbal label of that object. The exact nature of the link is not clear, but it may be that the gesture demonstrates the child's interest in an object. This may cause caregivers to produce the verbal label for this word more frequently, leading to that word's acquisition. Other research has shown that gesture vocabulary (the number of different meanings a child can depict in gesture) at 18 months can predict verbal vocabulary two years later (Rowe & Goldin-Meadow, 2009). As gesture can predict vocabulary in a more general scope, two years later, rather than the acquisition of specific words, it is possible that using gestures to convey meaning at a young age, may help to lay foundations of vocabulary learning later in childhood (Rowe & Goldin-Meadow, 2009).

Secondly, gestures have been shown to predict syntactic development. Rowe and Goldin-Meadow (2009) found that the number of speech-gesture combinations children used at 18 months predicted their sentence complexity at 42 months. Further, Iverson and Goldin-Meadow found that children use of certain types of gesture-word combinations can be used to predict the onset of the two-word stage of language development. Specifically, the onset of combinations in which gesture and speech provide different information (supplementary combinations; e.g. saying: '*Daddy*' and pointing at a bag) positively correlates with the onset of the two-word stage. In comparison, combinations in which gesture and speech give the same information (complementary combinations; e.g. saying '*bag*' and pointing at a bag) did not correlate. This suggests that deictic gestures can support children's language development. The mechanism, however, is not clear as to how gestures do this; it may be an indirect role such that gestures can elicit required input from a caregiver (Iverson & Goldin-Meadow, 2005).

Even after children have entered the two-word stage, speech-gesture combinations appear to foreshadow the emergence of more complicated structures (Özçalışkan & Goldin-Meadow, 2005). Özçalışkan and Goldin-Meadow (2005) looked at the pattern of argument-argument (e.g. '*Mama-chair*'/ '*Mama*' plus point to chair), argument-predicate (e.g. '*I paint*'/ '*you*' plus HIT gesture) and predicate-predicate (e.g. '*help me find*'/ '*I like it*' plus EAT gesture) combinations across 14- to 22-month-olds. They found, with a few exceptions, that for all three combination types, at a group and individual level, combinations occurred first in speech-gesture combinations and then later in speech only combinations. This suggests that gesture-speech combinations can be used to structure more complex utterances.

Özçalışkan and Goldin-Meadow (2009) followed children from 14-34 months, and found that although speech-gesture combinations are frequent, their predictive power decreases as children's linguistic abilities improve. More specifically, they found that speech-gesture combinations could predict the emergence of new verbal syntactic structures (e.g. argument-argument, argument-predicate and predicate-predicate). In contrast, the use of speech-gesture combinations with additional arguments (e.g., three or more argument structures such as a predicate with two arguments , such as '*Daddy gone*' + point OUTSIDE, or two predicates with multiple arguments, such as '*I like it*' + EAT gesture) was not related to the equivalent utterances in speech. That is, after children had acquired the basic structure, they did not use gesture to help them to add new arguments to them. This is interesting as it allows research to investigate when gestures do help to build syntactic structures and when they do not, which is useful to understand.

Iconic gestures, in particular, appear to have a special relationship to language development. Nicoladis (2002) videotaped eight French-English speaking bilingual children (3-4 years) during two free play sessions, one in each language. Children were categorised into either English dominant (4 children) or French dominant (4 children). This design enabled Nicoladis to investigate the link between language and gesture development, while removing age and general cognitive maturation as confounding variables. The results showed that children produced more iconic gestures when using their dominant language, compared to their non-dominant language. This pattern was not observed for conventional or deictic gestures. Further, results showed that when children produced iconic gestures, the mean length of utterance of the concurrent sentences increased, compared to when no iconic gestures were used, and compared to when conventional or deictic gestures were used. This indicates that iconic gestures have a closer link to language development, compared with other types of gestures.

Although the production of iconic gestures appears to be closely related to language development by 3-4 years, they do not appear to predict acquisition of verbs in the same way that deictic gestures predict noun acquisition (Özçalışkan, Gentner & Goldin-Meadow, 2013). However, there does seem to be an increase in iconic gesture frequency around the same time as they experience a large increase in verbs in their vocabulary (Özçalışkan et al., 2013). Further, children do seem to use iconic gestures to expand their repertoire of action related meanings (42% of meanings were only expressed in iconic gestures), by using them when there is a gap in their verbal knowledge (Özçalışkan et al., 2013). Thus, although iconic gestures do not predict later verb usage, they do appear to support it by allowing children to express action concepts they do not have lexical items for.

Gesture and language production in adulthood

The association between speech and gesture also extends into adulthood. For example, Frick-Horbury and Guttentag (1998) investigated the effects of gesturing on lexical retrieval after participants had been given definitions of a word. They found that participants who were allowed to gesture were able to retrieve more of the words than participants who were not allowed to gesture (see, however, Beattie & Coughlan, 1999, for a non-replication of this finding). Note that this relationship has also been observed with 6- to 8-year-old children (Pine, Bird & Kirk, 2007). It is interesting that when adult participants reported being in a tip-of-the-tongue state, those that were allowed to gesture used more iconic gestures than any other type of gestures (Frick-Horbury & Guttentag, 1998). This again suggests that there may be a special association between these types of gestures and speech.

How might gesturing benefit language production?

There are two main theories regarding how gesturing can help speakers. These theories do not contradict each other, such that both theories could be true at the same time. The first is the information packaging hypothesis, proposed by Kita (2000). According to this theory iconic gestures help to organise spatio-motoric information into packages that are more easily verbalised. Consistent with this theory, Goldin-Meadow (2000) argues that gestures give the speaker the opportunity to explore ideas that are difficult to verbalise. This can reduce cognitive load for the speaker and thereby facilitate learning as well as the thought process (Goldin-Meadow, 2000). The second is the lexical retrieval hypothesis (Rauscher, Krauss & Chen, 1996), which suggests that gesturing can facilitate lexical access as they can prime the semantic features associated with the intended lexical item.

So far, we have considered the effects of one’s own gesturing on their language development. The next section will investigate what effect seeing another person gesture, has on receptive language. Firstly we will consider when children begin to understand the meanings of iconic gestures, then we will review the relationship between gesture and language comprehension. Finally we will review the literature on the relationship between gesture and word learning.

Development of iconic gesture comprehension

Children begin to show understanding of iconic gestures at around 26 months (Namy, 2008; Namy, Campbell & Tomasello, 2004). When 26-month-olds were taught pairs of gestures and novel referent objects, they were only able to learn associations which included iconic gestures that depicted the action of an object, but not arbitrary gestures (Namy et al., 2004). Further, at 26 months, children can match iconic gestures to objects even when they have only seen the action of that object demonstrated and not seen the gesture until testing (Namy, 2008). This suggests that they understand the iconic nature of the gesture, in order to map it correctly. They have not simply learned the association between a gesture and an object (Namy, 2008). Tomasello and colleagues (1999) also found that at 26 months, children were able to match an iconic gesture (e.g. a HAT gesture, where a cupped hand represents a hat) to an object that had been used in that way but had its own conventional use (e.g. a cup that had been used for a hat). There has also been tentative evidence suggesting there are some signs of iconicity comprehension at 18 months (e.g. Namy, 2008; Tomasello Striano & Rochat, 1999). For example, In Namy’s (2008) study, 18- month-olds could select the correct toy better than chance when a gesture was used to request it, but this was not different to control trials, in which they were asked to retrieve any toy (e.g. *‘which one can you get?’*). So it appears that 2-year-olds have some ability to match an iconic gesture to an object.

This evidence suggests that by around 26 months, children have begun to understand the basic principle of symbolic distancing (Werner & Kaplan, 1963), such that they are able to match symbols (iconic gestures) to perceptually dissimilar referents (e.g. objects) (e.g. Tomasello et al., 1999). This shows that they have understood that one thing can be used to symbolise another, and these things do not have to be identical.

Evidence suggests that comprehension of iconic gestures, that is the understanding of the association between an iconic gesture and its referent, does not develop as a single ability; some iconic gestures appear to be more difficult for children to understand than others. For example, O’Reilly (1995) describes two types of gestures: body part as object (BPO), where the hand itself is used to represent an object (e.g. using an index finger across the mouth to depict brushing teeth) and imagined objects (IO), where the hand is used as if manipulating an object (e.g. using a fist as if holding a toothbrush to depict brushing teeth). In the study, children were shown a short video of someone producing one of these gestures and were asked what they thought the actor was pretending to do. Three-year-olds performed better after seeing a BPO gesture compared to an IO gesture. By 5 years, however, children performed equally well for both types of gestures. In terms of symbol formation, it appears that 3-year-olds can accept that hands can be used to represent other objects, but have difficulty in representing objects that are not represented physically at all. The same effect has also been shown in production as well as comprehension, such that young children spontaneously produce more BPO gestures compared to IO (O’Reilly, 1995; Boyatzis & Watson, 1993) For example, O’Reilly (1995) asked children to pantomime actions (e.g. ‘*can you pretend to talk on the phone*’) and found that 3-year-olds used a comparable amount of

BPO gestures to 5-year-olds but significantly less IO type gestures. Three-year-olds also have more difficulty in imitating IO gestures compared to BPO ones (Boyatzis & Watson, 1993). Similarly, despite the successes of 2-year-olds in previous studies in matching iconic gestures to objects, Mumford and Kita (2010, 2011) failed to demonstrate that children at this age could match iconic gestures to the actions of other body parts, such a legs or torso.

There is a large debate in the literature about whether iconic signs, in signed languages, are helpful to children during vocabulary development. Some researchers have argued that this does not influence children's language acquisition. For example, Orlansky and Bonvillian (1984) found that there were more arbitrary signs than iconic ones in children's first ten signs and in their vocabularies at 18 months. In contrast, other researchers have argued that iconicity does play an important role in language learning. For example, Thompson and colleagues (2012) had sign iconicity rated by adult British Sign Language users on a scale of 1-7 and found there was a main effect of iconicity on comprehension and production, such that the more iconic signs were the more likely young children (11-30 months) were to understand and produce them. It is possible Orlansky and Bonvillian's (1984) use of only three iconicity levels to rate signs was too coarse.

Further, it may be that the role of iconicity in sign language development changes over time. Thompson and colleagues (2012) found a significant interaction between age group and iconicity, such that iconicity had more influence on older children (21-30 months) than younger ones (11-20 months) in terms of sign comprehension and production. This is consistent with Orlansky and Bonvillian's (1984) study, whose infants were only 18 months old. It is possible that very young infants do not understand the iconic nature of the signs and so they cannot take advantage of this. As we have already seen, hearing children begin to understand iconic gestures around 26 months (Namy, 2008; Namy et al., 2004). This age is consistent with the older group of deaf children in the previous study, who were more influenced by iconicity in signs (Thompson, Vinson, Woll & Vigliocco, 2012). This issue relates to the current thesis, in which Chapters 3 and 4 investigate how hearing children's vocabulary development can be influenced by iconic gestures.

Extraction of information contained in gesture

Research has shown that children are able to learn from information that is only contained in gesture. For example, as discussed in section 2.1., Booth and colleagues (2008) found that young children can use points as a cue to select an unfamiliar referent. As we have just seen children can use iconic gestures or signs to identify referents from around 26 months (e.g. Namy, 2008). Kelly and Church (1998) have investigated whether older children can pick up information only contained in iconic gestures. For example, they showed 10-year-olds videos of children explaining Piagetian conservation type problems (for example, judging whether the amount of water is the same after it has been transferred to a different shaped container). In the videos, children gave incorrect answers in their speech, but sometimes provided additional information in their gestures, termed 'mismatches'. For example, a child might talk about the height of the two containers, but gesture about the differences in width. When asked how the children on the video explained their answer, participants included information that was solely expressed in gesture (Kelly & Church, 1998).

Children's ability to pick up information only expressed in gesture has important practical (as well as theoretical) implications. For example, Broaders and Goldin-Meadow (2010) found that after witnessing a scene, 5- and 6-year-olds included information from an interviewer's gestures, even when they were misleading (e.g. asking children '*what else was* *he wearing?*' and producing a HAT gesture, when the actor had not been wearing a hat, biased children to report that the actor was wearing a hat).

The research shows that a speaker's gesture can influence children's thinking and language comprehension. This has important implications, for example, we have seen that eye witness testimonies can be altered by an interviewer's gestures. How children can use nonverbal cues also has implications for social interactions. The current thesis investigates whether this type of gesture can help children to acquire new words.

Speech-gesture integration and comprehension of messages

It has been shown that toddlers can follow simple instructions better when they are expressed using speech-gesture combinations, compared to just speech, or to just gesture. Morford and Goldin-Meadow (1992) instructed 1- to 2-year-olds using a range of communicative techniques including two item speech ('*give the bottle*'), redundant speech-gesture ('*give the bottle*' plus point at the bottle), replacement speech-gesture ('*give*' plus point at the bottle), single word ('*bottle*') and single gesture (point at bottle). They found that hearing single words alone or seeing gestures alone elicited the target action less than any of the combinations. Importantly, they found that children performed better when they saw redundant speech-gesture combinations (where speech and gesture contain the same information) compared to speech alone, suggesting that gesture can add to children's comprehension even at this young age. Children also performed better compared to speech alone when they saw replacement speech-gesture combinations, suggesting that children this age find it easier to combine information from two modalities rather than combine two pieces of verbal information. Although it is not clear from this study that the children spontaneously understood the meaning of the gestures (both iconic and deictic), or whether they had become ritualised through interactions, the study does show that from very early on, children can use information in gesture to support their language comprehension.

It has also been shown that gestures can help the listener to understand the message later on in childhood. For example, although 5-year-olds are very good at using pointing gestures and speech alone to select the correct referent, there is an interaction when both are used together, such that the rely more on the clearest input (Thompson & Massaro, 1986). This means that the benefit of seeing gesture is greatest when the speech is ambiguous (for example, when a phoneme is in the midrange of a b-d continuum) (Thompson & Massaro, 1986). It has also been shown that gesture has more of an impact on speech processing when participants are in a nosy environment or have a hearing impairment (Obermeier, Dolk & Gunter, 2012). Gestures have also been shown to help adults disambiguate between two meanings of homonyms (Holle & Gunter, 2007), such that N400 effects (indicating semantic incongruency) were reduced when participants saw congruent gestures compared to when they saw incongruent gestures. This shows that gestures can improve listeners' comprehension of single, ambiguous words.

Similarly, it has been shown that iconic gestures can help children's comprehension of complex sentences. McNeil and colleagues (2000) gave children a box stacking task with complex instructions; children had to select the correct box for stacking based on the direction of an arrow (up/ down) and the placement of a rectangle in relation to a smiley face (above/below). The verbal instructions were accompanied with either matching gestures, mismatching gestures or no gestures. Older children performed the task at ceiling level for matching and no gestures, whilst performance dropped for mismatching gestures. Importantly, younger children performed better when they saw matching gestures, compared to when they saw no gestures or mismatching gestures. It appeared that when children found the verbal message more difficult to understand, gesture was able to boost performance. This hypothesis was supported in a second experiment with the younger children, who were then given simpler instructions in the task (box selection was based only on one feature). In this case matching gestures did not improve children's performance compared to when they saw no gestures (McNeil, Alibali & Evans, 2000). This study is important as it suggests that the reliance on gesture to support comprehension is not age dependent but more dependent on task difficulty.

Gestures have also been shown to improve children's pragmatic processing of verbal messages (Kelly, 2001). Kelly (2001) found that 3- to 5-year-old children understood indirect requests (e.g. '*I need to write something down*') far more often if they were accompanied by a pointing gesture and eye gaze cues (e.g. towards a pen) than if children just heard speech alone. This same effect has also been found for adults (Kelly, Barr, Church & Lynch, 1999).

Similarly, gestures have also been shown to improve children's comprehension of new concepts (Valenzeno, Alibali & Klatzky, 2003). Valenzeno and colleagues (2003) taught 4- and 5-year-olds the concept of symmetry, either with or without pointing and tracing gestures of shapes being explained. At post-test, children whose lesson had included gestures as well as speech, were more able to correctly identify shapes as symmetrical or not, compared to children who had not seen any gestures. Further, they were more able to provide explanations for why items were symmetrical or not (Valenzeno et al., 2003).

Finally, although this section has reviewed the literature on speech-gesture integration, there is still some debate about the automaticity of gesture-speech integration. Some researchers argue that it is automatic (e.g. Kelly, Creigh & Bartolotti, 2010a; Kelly, Özyürek & Maris, 2010b). For example, Kelly and colleagues (2010b) proposed the integrated systems hypothesis, whereby speech and gesture influence the processing of each other automatically.

Conversely, others argue that integration can be modified by communication difficulties (e.g. Obermeier et al., 2012). For example, as discussed above, Obermeier and colleagues (2012) only found evidence for speech-gesture integration when there was background noise or if listeners were hearing impaired. Therefore, when communication is problematic, the integration of gestures into speech comprehension appears to be increased. Further research is needed on this debate.

How might seeing gesture benefit language comprehension

We have seen that seeing someone gesture can support speech comprehension. Here we will review the possible mechanisms behind this effect. It should be noted that these mechanisms are not working exclusively and may be working at the same time to support language comprehension.

McNeil and colleagues (2000) suggest that gestures can benefit sentence comprehension in two ways. Firstly, as gesture and speech are complementary, gestures can offer an alternative way of understanding the same information. When children see congruent gestures, it is possible for them to understand from the speech, the gestures, or a combination of the two. The benefit of redundancy between speech and gesture on comprehension has also been suggested by Valenzeno and colleagues (2003).

Secondly, McNeil and colleagues (2000) suggest that gestures may be easier for children to understand due to their iconic nature, compared with the arbitrary nature of speech. Further, the authors argue that different types of gestures may be more beneficial in different circumstances, dependent on the type of information contained in the co-occurring speech (McNeil et al., 2000). For example, pointing gestures may be more useful when talking about objects or locations, while iconic gestures may facilitate comprehension when describing actions or functions (McNeil et al., 2000). This is consistent with the naturalistic finding of parents' own actions when introducing new words to young children (Clark & Estigarribia, 2011).

Gestures have also been argued to help ground language in the physical world (Valenzeno et al., 2003). Without gestures verbal messages may be too abstract for listeners to comprehend but gestures help them to build concrete representations of the language. The idea of grounding language in action is one we have already discussed in section 2.1.

Word learning and gesture

Research has shown that parents use gestures to introduce new words to young children (Clark & Estigarribia, 2011). Clark and Estigarribia (2011) found that parents typically used indicating gestures, such as pointing, to introduce parts and properties of objects, and demonstrating gestures (usually involving the object in some way) to introduce actions and functions of objects.

Research has shown that iconic gestures can influence first language word learning in very young children. In these cases, the children must figure out what the referent of the new word is and then learn it. McGregor and colleagues (2009) taught 20- to 24-month-olds the preposition: '*under*'. Teaching was conducted by showing two objects in an '*under*' relation, for example, a boat under a bridge for example. For some children teaching was supported with an iconic gesture, for example, one hand going underneath the other. Other children were taught by being shown a static picture of objects in an '*under*' relation. This condition was to control for children simply having a visual image, in addition to seeing the actual objects. The results showed that 2-3 days later, children who had seen iconic gestures had built a more abstract and robust representation of the meaning of the word '*under*'. This is a very promising result, although it is difficult to understand how children are using gestures, since there was only one gesture condition. It remains unclear whether gesture simply helped to maintain attention during teaching, or if they extracted meaning out of the gesture. The current thesis addresses this issue in Chapters 3 and 4, by comparing verb learning in two different gesture conditions.

Goodrich and Kam (2009) found that children were able to use iconic gestures to match a novel verb to a novel scene, when no other information was available. Children were taught two novel verbs in sentences such as: *'sometimes Sam likes to (NOVEL VERB 1 + GESTURE 1), and other times he likes to (NOVEL VERB 2 + GESTURE 2). Today Sam wants to go (NOVEL VERB 1)-ing, which toy will let Sam go (NOVEL VERB 1)-ing?'* The gestures depicted the action that the target toy made. The children had to map the iconic gestures to the correct scene, and then use that information to map the verbs to the correct scene. Three and four-year-olds were able to pick the correct toy. This shows that children can use information in gesture to build a representation of what a novel verb refers to. It is not clear, however, if children in this study understood that the novel verb only referred to the action in the scene. As we saw previously, when reviewing the literature on children's mapping of novel verbs, children typically believe that the actor and objects as well as the action are important features of a verb's meaning (e.g. Imai, Haryu & Okada, 2005; Kersten and Smith, 2002). In Goodrich and Kam's (2009) study it is not clear exactly what children had mapped the novel verbs to. They may have used the gesture to find the correct toy, and then mapped the verb to the action of the toy, to the action of that toy only when completed by that particular toy, or the entire scene. The study does provide good evidence that children can use iconic gestures to associate a novel word to a scene but more research is needed. In particular, it is important to ask children to generalise the novel verbs to novel scenes, in which different features have been changed. By doing this, we can investigate in more detail what features children have mapped the novel word to.

Iconic gestures have also been shown to support word learning in a second language, where the referent concepts of the foreign words are clear and known to the learners. For example, Tellier (2008) taught French 5-year-olds common English words, such as '*book*', '*rabbit*', over four weeks using short video clips for each word. To ensure that the referents of the words were clear, in the first week all the children saw an actor in a video clip produce an iconic gesture depicting the referent, and a video with a picture of the referent. After that the children were split into two groups: gesture and picture. Children in the gesture group were asked to repeat the gestures and words during training, while children in the picture group were asked to repeat the words. The results showed that children in the gesture group were able to produce more of the words (after seeing the gesture as cues) than children who were in the picture group (after seeing the pictures as cues). This study showed that gestures can help children to memorise words in a second language, although it is not clear if this effect was from observing the actor in the video gesture, or by replicating the gesture themselves. In another study, Tellier (2007) found that children's memory of words (in L1) was not affected by seeing an actor use an iconic gesture, but was improved by imitating that gesture themselves. Although the conclusions from this study are not clear, (the authors note that by making children imitate the speech may have distracted away from seeing a gesture), the results suggest that using gestures themselves can help children to build a more robust memory trace of the word (Tellier, 2007).

The benefit of gesture in a second language has also been demonstrated in adults' acquisition of foreign words. Kelly and colleagues (2009) taught English monolinguals Japanese words, such as '*Nomu means drink*'. Adults either heard the sentences without gesture, with a matching gesture (in this case one depicting '*drinking*') or with a mismatching gesture. They also had a repeated speech condition, in which the sentences were heard twice. The results showed that adults recalled and recognised more of the Japanese words if they were accompanied by a matching gesture. This performance was better than when the sentence was simply repeated. The repeated speech condition arguably offers the same quantity of information as the matching gesture condition, but this is offered in series rather than in parallel. This study is important as it shows that it is not simply that gesture offers extra information, but it is the type of information that is critical. Further, seeing mismatching gestures reduced adults' ability to learn the new word compared to seeing no gestures. This indicates that it is not that seeing co-speech gestures made the task easier, this effect is changed by the type of information contained in the gestures (matching vs. mismatching).

How might seeing gesture benefit word learning?

We have reviewed the literature suggesting that seeing someone gesture can support word learning in a range of contexts and in both a first and second language. Here we will consider the possible mechanisms behind these effects. As before, these mechanisms are not mutually exclusive and may be working simultaneously.

It appears that gestures help to capture and maintain learners' attention (e.g. Valenzeno et al., 2003; Clark & Estigarribia, 2011). It is possible that gestures can make the learning environment more interesting and may therefore help to maintain attention during word learning, which in turn can improve performance. For example, Valenzeno and colleagues (2003) argued that children who saw a verbal only version of the lesson on symmetry were less attentive, as measured by increased head turns away from the screen, compared to children who saw a verbal and gestural explanation. Further, Clark and

Estigarribia (2011) found that when parents were teaching new words to their 1-year-olds they were more likely to lead the interaction with a gesture. This pattern was not found for 3-year-olds, whose parents were equally likely to start the interaction with a gesture, speech or both simultaneously. The authors argue that the parents of younger infants lead with gestures more often in order to help establish attention (Clark & Estigarribia, 2011). Note, that this account can also be applied to the question of how gesture improves speech comprehension. It is clear, however, that capturing and maintaining attention is not the only function of gesture, as there is a difference between seeing congruent and incongruent gestures (e.g. Mumford & Kita, 2011; Kelly, McDevitt & Esch, 2009).

It has been suggested that gestures can help children to learn new words by reducing cognitive load (Goldin-Meadow, 2000; McGregor, Rohlfing, Bean & Marschner, 2009), although there is no direct evidence for this account to date. McGregor and colleagues (2009) argue that gestures can help to make the referents of novel words more salient, which frees up important cognitive resources for processing and representing the new word.

Previous research supports the idea that gestures can influence children's ability to select referents for novel words. In particular, evidence suggests that gestures can help children to associate a novel word to a particular scene (Goodrich & Kam, 2009). This study however, did not show that gestures can be used to select a referent within a scene. To understand whether iconic gestures can help children to pick out a referent within a scene Mumford and Kita (2011) taught children novel verbs and then asked them to generalise the verbs to either a different actor (correct choice) or a different manner (incorrect choice). Teaching was accompanied with congruent iconic gestures that matched the referent action, incongruent iconic gestures that matched a distracter at test, or no iconic gestures. The results showed that children who saw incongruent iconic gestures performed worse than the other two groups, such that they could not generalise the novel verbs better than chance. These results support the idea that iconic gestures can influence verb learning. This idea, however, was only supported by the performance of the children in the incongruent gesture condition; there was no difference in performance between children who saw congruent gestures and those who saw no gestures. The incongruent iconic gesture condition lacked ecological validity and so it is not clear if this result can be extrapolated to real world word learning. Chapters 3 and 4 will address this issue by investigating the role of iconic gestures in verb learning further, without using incongruent iconic gestures.

Once referents have been identified, gestures appear to help learners to build a more robust and abstract representation of the new word (McGregor et al., 2009). Similarly, Feyereisen (2006) found that memories for sentences were better when they had been accompanied by iconic, rather than beat gestures. Kelly and colleagues (2009) argue that this may be because the gestural and verbal information integrates and produces a strong, multimodal representation. Further, Kelly and colleagues (2009) argued that seeing iconic gestures helped to associate the word in participants' first and second languages to create a more stable memory trace of the word.

It should be noted, that the benefit of speech-gesture combinations when learning new words, is not simply that listeners get twice as much information (some in speech and some in gesture) compared to speech only conditions. Kelly and colleagues' (2009) study of word learning in L2 with adults included a repeated speech condition, such that the speech only and speech-gesture received equivalent amounts of information. The results showed that the speech-gesture group outperformed the repeated speech group (Kelly et al., 2009).

This section has reviewed the literature on the relationship between gestures and language development. Chapters 3 and 4 aim to further our understanding of this relationship by investigating exactly how children use information contained in a speaker's iconic gestures, when learning new verbs.

CHAPTER 3

HOW ICONIC GESTURES CAN INFLUENCE CHILDREN'S LEARNING OF CHANGE-OF-STATE VERBS

3.1. Goals and Motivation

This paper investigated whether iconic gestures were able to influence children's acquisition of novel change-of-state verbs. These are verbs in which the manner of motion is not critical to the verb's meaning but the outcome at the end is. These type of verbs are useful to study as they contain (at least) two clear features: manner and end state, both of which can be easily and naturally gestured.

The current study taught children one change-of-state verb over four exemplars. In the first exemplar, the meaning of the verb was ambiguous: it could refer to the manner in the scene or to the change of state. From the second trial onwards, however, only a change-of-state interpretation was plausible. This was because the manners in the exemplars were different, but the end states were always the same. Training was accompanied with either an iconic gesture depicting the end state, an iconic gesture depicting the manner or no gesture. End state gestures should have been helpful as they highlighted the critical feature, whereas manner gestures should have been misleading as they highlighted an irrelevant feature. Importantly, although manner gestures may have highlighted an irrelevant feature they were not mismatching as in previous studies (e.g. Mumford & Kita, 2011), since they did match the manner in that exemplar. In Mumford and Kita (2011) only the mismatching gestures had an influence on verb learning, and this may have been due to the lack of ecologically validity of these gestures. The current design aimed to rule out this account.

This study aimed to further previous work on the role of iconic gesture and word learning in a number of ways. Firstly, by asking children to generalise the novel word to a novel scene, the features they believed to be more important could be inferred, reflecting their representation of the novel word. Secondly, by comparing performance of two different gesture conditions, we could investigate whether the content of the gesture was important, rather than the presence of any gesture. Finally, as the same verb was taught over four trials, the influence of gesture could be investigated in relation to how ambiguous a novel word is.

3.2. ARTICLE 1

HOW CHILDREN USE ICONIC GESTURES TO LEARN NEW CHANGE-OF-STATE VERBS

Abstract

Children appear to be able to use iconic gestures when learning new words (e.g. McGregor, Rohlfing, Bean & Marschner, 2009; Goodrich & Kam, 2009). The nature of this relationship, however, remains unclear. The current study investigates whether iconic gestures can help children to understand change of state verbs, taught over several exemplars. Teaching was supported with either a gesture that highlighted end state (helpful), a gesture that highlighted manner (misleading), or no gestures. The results showed that although children could match gestures to videos, gestures did not affect verb learning. The data appear to show a floor effect suggesting that this paradigm is not effective in assessing children's verb learning.

Key Words: Verb Acquisition, Iconic Gesture, Children, Iconicity, Change-of-State.

In English, some verbs refer to a particular action (e.g. to throw), while others refer to a change in state (e.g. to break). Research has shown that young children appear to understand that end states are an important aspect to a scene (e.g. Papafragou, 2010; Behrend, 1990). In contrast, older children often apply change-of-state verbs incorrectly, such that they believe that the manner is critical rather than the end state (Gentner, 1978; Gropen, Pinker, Hollander, & Goldberg, 1991). In term of acquisition, research has shown that children often believe that manner is an important feature of a novel verb's meaning, (e.g. Forbes & Farrar, 1995).

Research has shown that actions made upon an object can help children to understand the referent of novel words (e.g. O'Neill, Topolovec, & Stern-Cavalcante, 2002; Kobayashi, 1997, 1998). The current study will extend this work by investigating whether iconic gestures, rather than manipulative actions on an object, can focus attention onto particular aspects of a scene while learning new verbs.

Iconic gestures have also been shown to support both second (Tellier, 2008) and first language word learning (McGregor, Rohlfing, Bean & Marschner, 2009). It was not clear, however, if gestures make the referent of the word clearer and, therefore, reduce cognitive load (as suggested by McGregor et al., 2009). Alternatively, gestures may make the learning environment more interesting and so help to maintain attention towards the task (See Valenzeno, Alibali & Klatzky, 2003). This study will address this issue by comparing two gesture conditions with different meanings. If gestures' meanings matter, the two groups of gestures should have different impacts on participants' behaviours.

Research has also investigated whether iconic gestures can help children to learn novel verbs (Goodrich & Kam, 2009). In this study, however, children simply had to learn which verb referred to which scene, and it remained unclear whether children understood that the verb referred to the motion in the scene, or the scene as a whole. The study will address this issue by asking children to generalise the novel verb to novel scenes. This allows us to infer which feature of a scene children believe is important to the verbs meaning and which isn't.

The current study investigated children's ability to utilise information in iconic gesture when learning novel change of state verbs. Iconic gestures may be able to highlight end state as the critical feature of a novel verb's meaning. Iconic gestures can be used to depict relevant aspects of a scene, which then become highlighted in that scene. Thus, if the end state of an action is depicted in gesture this end state should become more salient to the listener. This increase in saliency may help children to recognise and understand the importance of the end state in the novel verb's meaning. Further, as end-state gestures will not include any information about manner, such gestures may help to draw attention away from manner, which is not critical to the verb's meaning.

Previous research has shown that iconic gesture can influence children's language comprehension (McNeil, Alibali, & Evans, 2000). McNeil and colleagues (2000) found that the more complex the message is, the more iconic gestures had an influence. This will be addressed in the current study, as the meaning of the novel verb is ambiguous in the first trial, but from the second trial onwards only a change-of-state interpretation is plausible. The study will investigate whether the use of iconic gestures in word learning is influenced by how ambiguous the word is.

Current Study

The current study will teach children a novel change-of-state verb. Participants will be taught one change-of-state verb, over four trials. Each exemplar will show a different manner but the end state will be consistent. The training will either include no iconic gestures, iconic manner gestures or iconic end-state gestures. The manner gestures are intended to be misleading, as they guide attention to an aspect of the scene which is irrelevant to the verb's meaning. Whereas end-state gestures are intended to be helpful, as they highlight the feature of the scene which is critical to the verb's meaning.

If gestures help word learning by providing a more interactive and engaging learning environment, then the content of gestures should not influence children's performance. Therefore, if this were true, both children who saw manner and end state gestures would select the correct video more often than children who saw no gestures.

If children can use information contained in iconic gestures to guide their representation of a novel verb's meaning, it was predicted that children who saw end-state gestures would select a change-of state interpretation more often than those who saw manner gestures, or no gestures. Further, it was predicted that children who saw manner gestures would select the incorrect choice more often than children who saw no gestures as the manner gestures would consistently guide their attention to an irrelevant feature of the scene.

Finally, it was predicted that all children's performances would improve over the trials, as more information about the verb was being revealed. Further, if it is the case that children try to incorporate information from gesture to understand the verbs meaning, then a gesture condition- trial interaction was predicted. This is because in the first trial, both end-state and manner interpretations of the novel verb are plausible; further examples are needed to be sure of the true meaning. Children may, therefore, be more influenced by the information seen in gestures. As the trials continue, however, children may see enough video exemplars to understanding the meaning of the verb, without relying on any additional information from gestures. This means that gesture may have a larger effect in the first trial, when the meaning is ambiguous, but this effect decreases as the experiment continues, as the videos provide sufficient information to build a more accurate understanding of the verb's meaning.

Method

Participants

Forty-eight 3-year-old children (21 females and 27 males; *M*= 41.71 months, *SD* = 3.27, range: 36-47months) took part in the experiment. The participants were recruited from nurseries around Warwickshire, England and received a sticker in return for their participation. Children were pseudo-randomly assigned into a gesture condition, such that they were assigned into a group before the experimenter met them, for example working down an attendance list or the order in which consent forms were given to the experimenter, whilst taking care to balance groups, (e.g. in terms of sex).

Design

The independent variable was the gesture condition, which was a between-subjects factor and had three levels: Iconic End-state Gestures, Iconic Manner Gestures and No Iconic Gesture. The dependent variable was binary, either correct (same end state choice), or not (same manner choice).

Stimuli

Video clips

The experimental stimuli consisted of 16 video clips, each lasting between 9-15 seconds. All videos started with a white piece of paper on a table and black material was either added, or revealed, to leave an end state of either black and white stripes, or a black triangle on a white background. See Figure 3.1. for images taken from four video clips.

There were eight different manners used in the study, such as printing and rolling. Each manner was used in two videos: one resulting in a stripy end state, and one resulting in a triangular end state. Details of all the video clips can be found in Appendix 1.

The eight manners were organised into four video groups. These were selected such that the end states were as similar as possible to each other. For example, printing and rolling were in the same video group as they both used black paint to achieve the end state. The video groups were also designed such that iconic gestures depicting the two manners in a given group were distinct. Each video group was made of four video clips in total (two manners x two end states). See Figure 3.1 for an example of the videos that make up one video group.

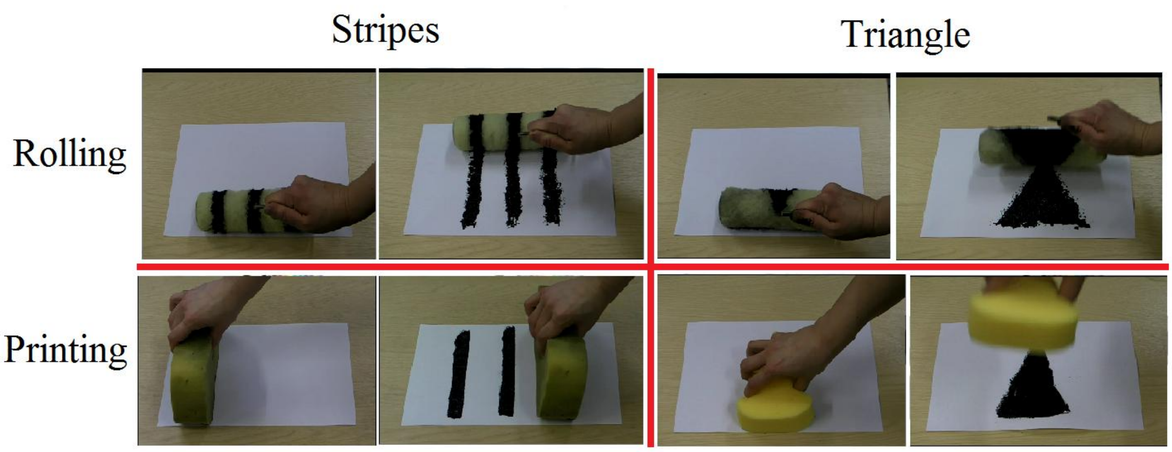


Figure 3.1. Still images taken from the four videos which made up Video Group 1.

In the test phase of the experiment two videos would play simultaneously, side-by-side during trials. The videos that were shown together were taken from within a video group, and between them showed the two different manners and end states. In Video Group 1, for example, rolling stripes was presented with printing a triangle, and rolling a triangle was presented with printing stripes. The videos that were shown together were matched for length, within one second.

Iconic Gestures

There were two types of iconic gestures in the study: manner and end state. Each of the eight manners could be depicted by one of three iconic manner gestures, which depicted the motion of the hand in the video. For example, one of the manner gestures was performed as if the hand was holding an imaginary object and making vertical movements. This single gesture was used to depict both the printing and placing manners. See Appendix 2 for details.

Similarly, each of the end states (triangle and striped) could be depicted by one of three iconic end state manners. For example, one of the end state gestures was the index finger tracing lines up and down. This single gesture was used to depict the striped end state when it was achieved by clearing, brushing and rolling materials. Even though this gesture could depict all of the striped end states, the study used three end state gestures to depict striped end states (as well as three to depict triangular end states) as there were also three types of manner gestures. This meant that children in both the manner gesture condition and the end state gesture condition would see an equal number of different gestures. Details of all the iconic gestures can be found in Appendix 2.

Note that none of the manner achieved an end state by painting, drawing or otherwise tracing the outline of the end state. This was consciously decided to reduce the possibility that end state gestures, which included tracing the lines of the end state, were interpreted as manner gestures.

Stimuli pre-test

A pre-test was conducted to ensure that children could match the iconic gestures to their referents in a two-way forced choice task (full details in Appendix 3). Twenty-four 3-year-olds (11 females, M = 42.02months, SD = 3.30) who did not take part in the main experiment, matched iconic end state gestures (t (23) = 3.98, p=.001) and iconic manner gestures (t (23) = 4.17, p<.001) to the correct video above chance. Finally, the results of a likelihood ratio test comparing two models (one with and one without gesture type as a fixed effect) found that children's performance did not significantly differ between end state and manner gestures (χ^2 (1) = 1.095, p>.1). See Appendix 3 for details.

Procedure

Participants were tested individually in a quiet area of their own nursery. Stimuli were presented on a 20" screen. First, participants completed four practice trials, in which participants were asked to point to photos of familiar objects. Practice trials were designed to familiarise participants with the pointing procedure. There was no practice of pointing to videos so as not to prime children's attention to any aspects of video stimuli before the main experiment began.

The study then moved onto the experimental phase, which consisted of four trials. Each child was taught the novel verb '*to dax*'. For half of this children '*to dax*' meant ' *to make something stripy*' and for the other half it meant '*to make something into a triangle*'. All four trials taught the same verb using four different manners (e.g. gathering, rolling, pushing and placing).

Each experimental trial consisted of two stages: training and testing. In the training phase participants saw a video clip of an actor performing the target action (for example, rolling black stripes onto white card), and heard the training sentence '*Look! She's daxing it!*' (for the first trial only) and '*Look! She's daxing this too!*' (for subsequent trials). Both the video clip and the training sentence were then repeated.

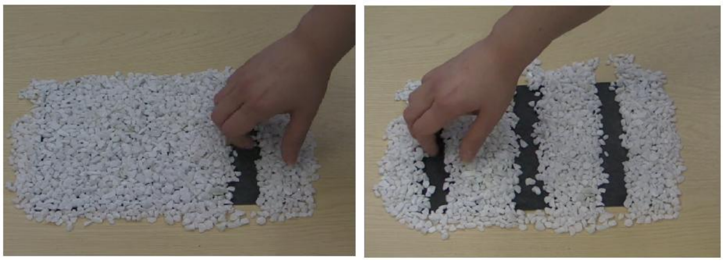
Previous research has found that using the adverb '*again*' can alter 4-5-year-olds' interpretation of the meaning of a novel verb (Wittek, 2002). When children hear the word '*again*' they are more likely to infer a change-of-state interpretation of a novel verb. This experiment will, therefore, deliberately not use the word '*again*' to avoid biasing children towards an end-state interpretation. The training sentence from the second trial onwards is *'Look! She's daxing this too'*. This sentence was selected to clarify with participants that the video clip being viewed, was another exemplar of the same verb depicted in previous video clips.

The gesture manipulation occurred at the training phase. If the training video depicted stripes being rolled on to a piece of card, for example, children in the iconic end-state gesture condition saw a gesture highlighting stripes, children in the iconic manner gesture condition saw a gesture depicting a rolling action and children in the no iconic gesture condition saw no gestures.

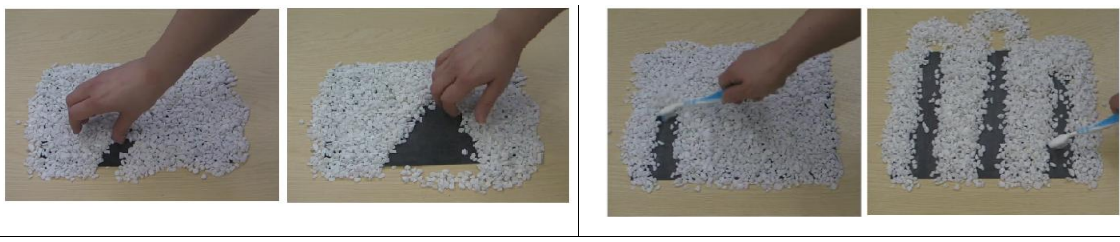
In the test phase participants saw two videos, side-by-side, playing simultaneously and were looped. Participants were asked '*Which one's daxing it?*' One video showed a different manner resulting in the same end state. This was the correct choice. If children had an change-of-state verb interpretation they would select this video. The other video showed the same manner now resulting in a different end state. This video was the incorrect choice. If children had a manner verb interpretation they would select this video. See Figure 3.2 for an example of the entire experiment. The test phase was the same for all participants; the experimenter used no iconic gestures.

Trial 1

Training



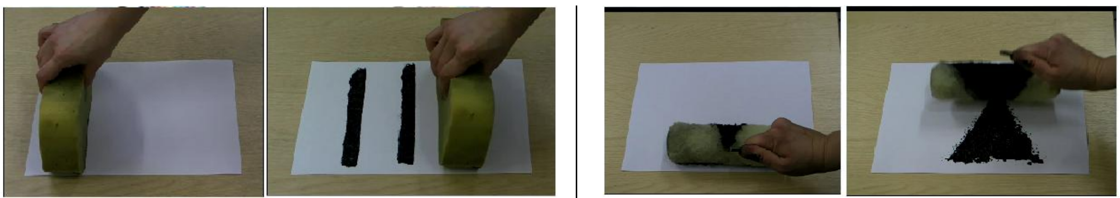
Testing



Trial 2

Training

Testing



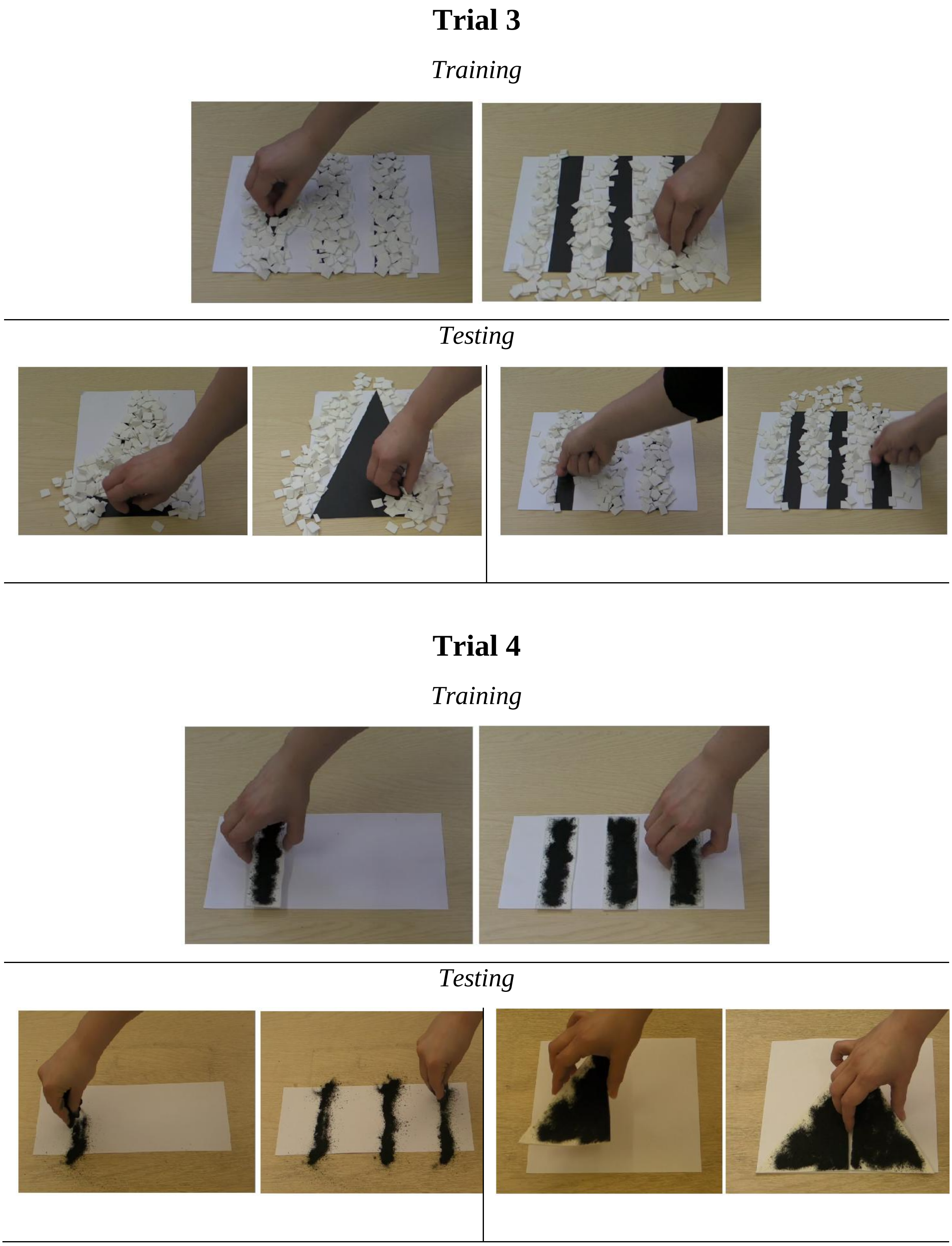


Figure 3.2. Still images taken from videos to demonstrate the structure of the entire experiment.

The trial ended when the participant made their selection or, if the participant did not choose a video, after the question had been asked five times.

Throughout the entire experiment, the experimenter never used pointing gestures to direct attention towards the screen. This was to control for any effect that seeing any types of gesture may have on children's performance, simply by being in a more interactive learning environment, and therefore more engaged or motivated.

Counterbalancing

The order that video groups were shown to participants was rotated, such that all four video groups appeared equally often in all four trials. Between-subject counterbalancing ensured that all videos were used equally often as the training video, the target video at test and the distracter video at test. This resulted in 16 counterbalancing orders (four videos per video group x four orders of video groups). Finally, the correct choice appeared equally often in the left and right position for all participants.

Data Analysis

Although six children only selected videos from one location (left or right video), they were not excluded from the analysis. This was because there were only four trials per participant so these responses could have been informed and not merely a side-bias. One trial from one child was removed as they selected a video before they had begun to play.

Results and discussion

Effect of trial and gesture condition

First, the data was split into the four experimental trials, to investigate any changes in performance as the experiment continued. Figure 3.3 shows the trajectory of the three gesture conditions across all four trials.

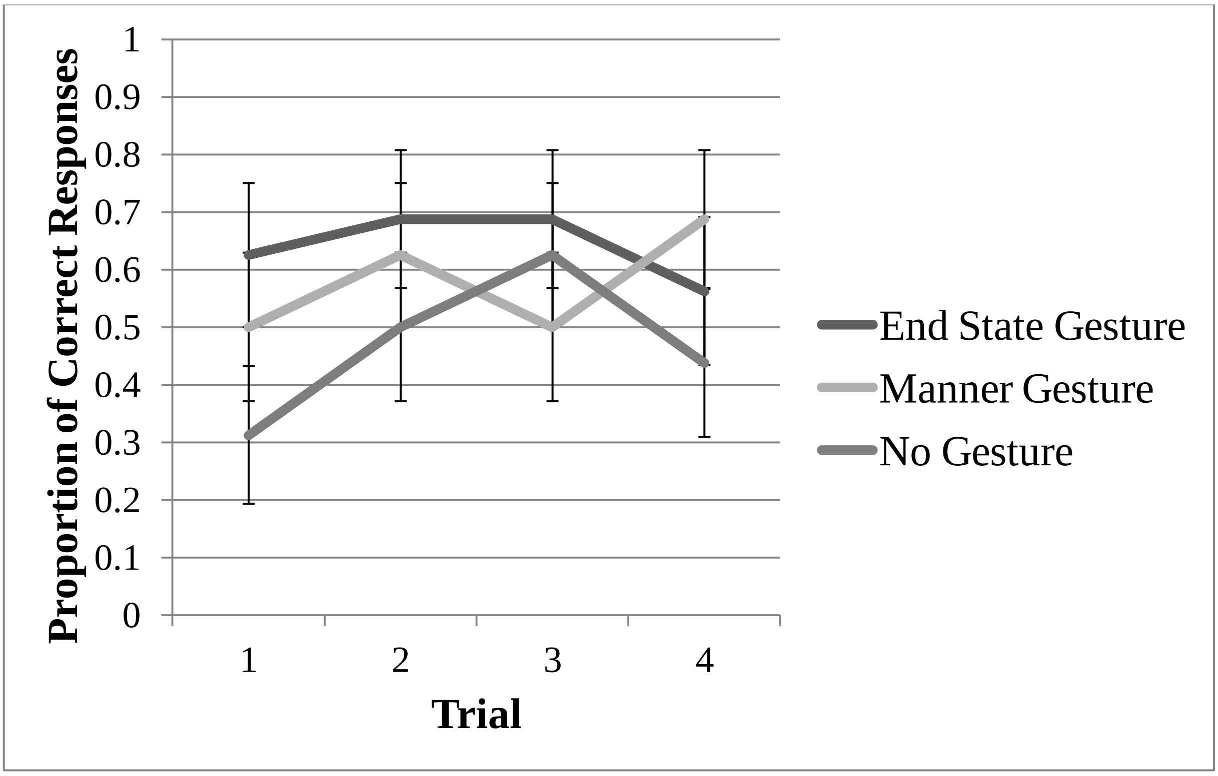


Figure 3.3, The trajectory of the proportion correct of the three gesture conditions across all four trials. The error bars show standard error of the participant means.

As each child only contributed once to each data point, a generalised linear mixed effects model was used to analyse the data. See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013). As children's performance was predicted to improve across trials, this factor was coded as numerical (continuous) rather than categorical.

First two models were compared in order to investigate whether there was an interaction between trial and gesture condition. The first model included the following fixed factors: gesture condition (end state, manner and no gesture), trial (numerical variable) and the interaction between gesture condition and trial. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercepts by participant, 2) random slopes by participant for trial (but not random slopes by participant for gesture condition since this manipulation was between participants), 3) correlations between the random intercept by participant and random slopes by participant for trial. The second model was the same except that only the fixed effects for gesture condition and trial were included; the interaction between gesture condition and trial was not included.

The results of a likelihood ratio test revealed that the interaction between gesture condition and trial was not significant (p>.1). See Figure 3.3 for the descriptive results. Table 3.1 reports the parameters of the model without the interaction but with the main effects of gesture group and trial (Model 1).

Table 3.1

Fixed effects of Model 1 (fixed effects of gesture condition and trial but not the interaction)

	B	*SE*	*z*	*p*
Intercept	0389	0.502	0.775	.438
Gesture Condition- Manner	-0.377	0.515	-0.733	.464
Gesture Condition – No gesture	-0.902	0.513	-1.758	.079
Trial	0.147	0.139	1.056	.291

Note, for the gesture manipulation, the end state gesture condition was taken as the reference group and the other gesture conditions were contrasted to this.

In order to test whether there was a main effect of gesture condition two additional models were compared. The first included gesture condition as a fixed factor and random intercepts by participant. The second model only included a constant and random intercepts by participant. The results of a likelihood ratio test revealed that there was no main effect of gesture condition ($p>.1$).

Finally, in order to test whether there was a main effect of trial two additional models were compared. The first included trial as a fixed effect. The model also included random intercepts by participant, random slopes by participant for trial and the correlations between the random intercept by participant and the random slope by participant for trial. The second model only included a constant and the same random effect structure as the first. The results of a likelihood ratio test revealed that there was no main effect of trial ($p>.1$).

Comparison to chance

The data for each gesture condition was collapsed across trials and compared to chance, using planned t-tests. The results showed that children who saw no iconic gestures or manner iconic gestures performed at chance (p>.1), while children who saw end state gestures performed marginally above chance (t (15) =1.781, p=.095). Overall, the results reflect a floor effect, with no effect of gesture, and with children largely performing at chance level, see Figure 3.4.

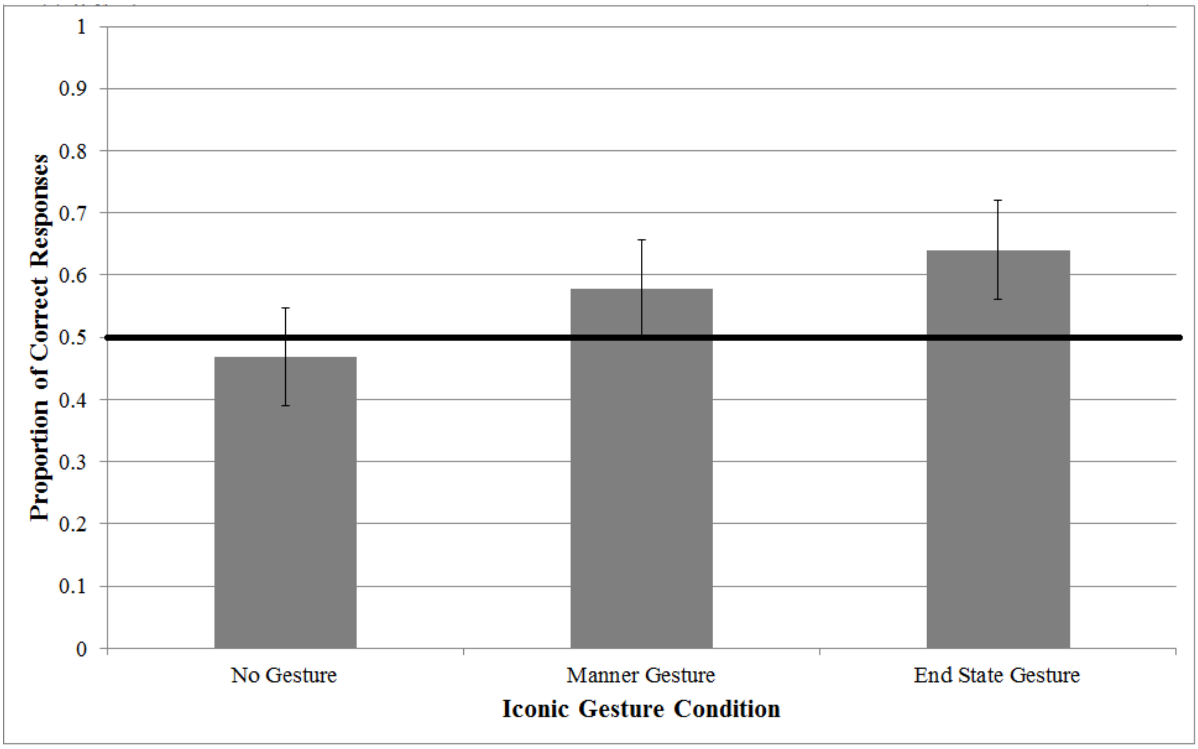


Figure 3.4, The mean proportion correct for all three gesture condition, collapsed across all trials. The thick line represents chance (.5) and the error bars represent standard error of the participant means.

Discussion

The current study investigated how children use iconic gestures when learning new words. The results showed that, despite being able to match the gestures to their referents, there was no influence of gesture on learning.

The results showed that there was no effect of iconic gesture. This suggests that the children were not integrating information seen in gesture into their representation of the novel word's meaning. Further, an interaction between iconic gesture group and trial was predicted, such that when the meaning of the verb was ambiguous (at the start of the study), gesture would have more of an influence than when the meaning of the verb was clearer (at the end of the study). However, no such interaction was observed. This study, therefore, may provide evidence that children do not use information contained within iconic gesture during verb acquisition, even if the meaning of the verb is unclear from the context.

This account is inconsistent with previous studies which found that gestures did enhance word learning (e.g. McGregor et al., 2009). This difference may be because the studies investigated different types of syntactic categories, and verbs may not benefit from gestures in the same way that other categories do (e.g. prepositions).

It is perhaps more likely that the current null effect of gesture was driven by an overall floor performance. This account is supported by the chance level performance across all the groups (although the end state gesture group did show performance marginally better than chance). Similarly, the study found no effect of trial, such that children did not improve even as more information was made available to them through the video stimuli. This result was unexpected and suggests that children could not learn effectively from the videos in the study.

The results, therefore, suggest that the task in the study was too difficult for 3-year-old children to complete.

Overall, the results demonstrated a floor performance and suggest that the paradigm used was not a suitable one to assess children's verb learning. The rest of the discussion will, therefore, focus on methodological issues and how to improve any issues for future studies.

One potential issue with the current methodology was the stimuli used. In particular, too much novel information can hinder children's ability to learn novel words (Kersten & Smith, 2002). The stimuli may have contained too much information for children to be able to focus on the task. Research has shown that children can learn a novel word more effectively if they view a single exemplar of the word, repeatedly, compared with viewing several exemplars of the word (Maguire, Hirsh-Pasek, Golinkoff & Brandone, 2008). One explanation for this is that if children see several novel situations they become distracted by the extra features of that scene, such as the actors and the instruments used, so much so that they cannot focus on what is common between videos (Maguire et al., 2008). In contrast, when children see a single video repeated, they become habituated to the features and can focus on the meaning of the verb (Maguire et al., 2008; Kersten & Smith, 2002). In the current study, the manners which resulted in the two end states were very varied, involving different materials and objects as well as different manners. Further, in three of the four video groups the materials changed between training and test, for example using a roller in training then seeing a roller and sponge at test. The use of so many different materials may have been very distracting for the children, so much that they could not focus on what was constant over the videos, (i.e. the end state), leading to floor performance.

Change-of-state verbs can be applied to a range of different exemplars, for example the word '*break*' can be applied to anything that has the capacity to be damaged or ruined, physically or metaphorically (e.g. a heart). Having such a wide variety of meanings may make these words very difficult to fully understand, as so much varies over exemplars while relatively little is held constant. It may be that in order to teach change-of-state verbs effectively, it is most useful, initially at least, to show children similar exemplars rather than exemplars that cover the entire spectrum of the word's meaning at once.

Next study

The next study (Chapter 4) will use a similar paradigm to the current one but make subtle changes in order to make the task easier for children. In particular the following changes will be made: 1) different verbs will be taught for each trial, rather than one verb seen over multiple trials, 2) the materials in each trial (training, and both test videos) will be as similar as possible to each other. These changes will now be discussed further.

1) Teaching several different verbs, rather than one verb several times.

This should simplify the study as children will not have to build up a representation of a verb's meaning and then keep updating it as more information about the true meaning is revealed through different exemplars. By simplifying the study like this, it should be clearer to see what children can learn, if anything, from iconic gestures, without the distraction of multiple exemplars.

This change will also mean that there is no correct answer, as an end state and manner interpretation will both be equally plausible meanings of the verb. This will make both types of gestures equal, rather than end state being helpful and manner being distracting.

2) The materials in each trial will be as similar as possible to each other.

This should reduce the effects of novelty, as the materials seen at test will not be completely novel to the children (as they are also in the training video) and so they should be less distracted by extra features of the videos, and more able to focus on understanding the meaning of the word.

General conclusions

To conclude, the current study found that although children could understand the iconic gestures, they had no effect on verb learning. Due to an overall poor performance from children in all conditions, firm conclusions could not be drawn about the nature of this null effect. The paradigm used in the study is, therefore, ineffective at measuring children's word learning abilities and so should be modified for future work.

CHAPTER 4

HOW ICONIC GESTURES CAN ALTER CHILDREN'S REPRESENTATIONS OF NOVEL VERBS

4.1. Goals and motivations

Chapter 3 investigated how iconic gestures may influence children's understanding of change-of-state verbs, such as '*to break*'. The study, however, found a floor effect, possibly due to methodological features making the task too difficult for children this age. The current study aimed to address these issues to make the task more age appropriate. There were two issues in particular that were improved for this study. The first was that the current study taught several different verbs, rather than teaching one verb with multiple exemplars. The latter of which requires children to continually update their representation of the verb as new information is seen. Teaching different verbs, therefore, made the task easier on children's working memory, as they only had to remember novel verbs for a short time (the gap between training and test was only a few seconds). The second improvement is that more similar materials were used in the study, such that no tools were used at test that did not appear in training. This is because novelty can impair children's learning of novel words (Kersten & Smith, 2002).

These changes also resulted in all the verbs' meanings being ambiguous. In Chapter 3, after two exemplars of the verb had been seen, only a change-of-state interpretation was possible. In the current study though, both manner and change-of-state interpretations were always plausible. This allowed gesture to have more of an influence on interpretations, as there was no '*right*' answer.

The current study, therefore, investigated the role of seeing iconic gestures on children's interpretation of novel, ambiguous verbs. To do this, the same paradigm seen in Chapter 3 was used: training of a novel verb through a video exemplar that was either accompanied by an iconic gesture (end state or manner) or not, and testing in which two videos played side-by-side, one with the same end state and the other with the same manner.

4.2. ARTICLE 2

CHILDREN USE GESTURE TO INTERPRET NOVEL VERB MEANINGS

Abstract

Children often find it difficult to map verbs to specific referents within complex scenes, often believing that additional features are part of the referents. This study investigated whether 3-year-olds could use iconic gestures to map novel verbs to specific referents. One-hundred-and-twenty children were taught verbs that could be interpreted as change-of-state or manner verbs, while presented with either manner, end state or no iconic gestures. Children were then presented with a choice that forced them to generalise either on the basis of manner or end state. Results showed that children who saw manner gestures showed a stronger manner bias compared to the other groups. Thus, the specific feature of an event encoded in gestures guides children's interpretations of novel words.

Key Words: verb acquisition, iconic gesture, children, iconicity.

When people speak, they often spontaneously produce gestures. Gestures play complex and important roles in communication (Hostetter, 2011; Kendon, 1994). We investigated how gestures by adults influence children's word learning. Among various types of gestures, the current paper will focus on iconic gestures. These are gestures that, either in hand shape or movement, depict action, movement or shape based on similarity between the gestural form and referent (McNeill, 1985).

The Problem of Verb Learning

Children learning English typically begin to use nouns before they use verbs (e.g. Goldin-Meadow, Seligman & Gemlan, 1976, Bornstein, Cote, Maital, Painter, Park, Pascual et al., 2004). Experimental studies showed that 3-year-old children, for example, struggle to generalise new verbs outside of the context in which it was first encountered (e.g. Imai, Haryu & Okada, 2005) especially if features of the context are novel (e.g. Kersten & Smith, 2002). It has been argued that it is difficult for children to pin-point what aspect of a complex scene is the referent of a novel word in an ostensive word-learning situation (e.g. Gentner, 1982). This is commonly known as "Quine's (1960) problem". Although this problem is traditionally associated with noun acquisition, the same issues arise with verb learning too. Gentner (1982) argues that nouns are easier to learn than verbs, since they have a more transparent mapping to the perceptual world. In contrast verbs have less transparent mappings; children have to extract and package various aspects of the relations between objects (Gentner, 1982). Verbs often refer to complex actions, including various participants and objects (Imai et al., 2005) as well as varying outcomes. Further, the referents are often dynamic and fleeting (e.g. an action). Gleitman and Gleitman (1992) describe several problems children face when learning verbs, including how the word is often not heard at the time of the event itself and how some verbs cannot be seen at all (e.g. internal states '*to know*'). They also highlight how complex the contexts are when verbs are heard, and the difficulty in trying to understand which feature the verb is expressing (Gleitman & Gleitman, 1992). Despite these difficulties, in real life, children this age appear to have begun to comprehend and produce verbs (e.g. Goldin-Meadow et al., 1976). The discrepancy between experimental and real-life learning situations may arise because real-life situations may provide a richer set of contextual cues, such as speech-accompanying gestures. The current study investigated whether co-speech gestures can bias children's interpretation of a novel verb towards either a manner verb (such as '*to kick*') or a change-of-state verb (such as '*to break*').

Manual Actions and Word Learning

Adults' body movements can influence children's word learning performance. Manipulative actions made upon novel objects, when learning a novel label, influence children's understanding of what novel labels refer to. For example, Kobayashi (1997) found that, when teaching novel words, actions which highlighted shape (e.g. rolling a glass egg) or material (e.g. looking through the glass egg) helped children to assign labels to particular properties of objects. Further, these actions helped children to pinpoint a particular aspect of an object better than a pointing gesture (Kobayashi, 1998). Similarly, O'Neill and colleagues (2002) taught children novel adjectives, and found that actions made upon objects, which highlighted texture, helped children to identify the meaning of these words.

Gestures and Word Learning

Iconic gestures have been shown to support word learning for a range of word types in both first (McGregor, Rohlfing, Bean, & Marschner, 2009; Goodrich & Kam, 2009) and second language acquisition (Tellier, 2007, 2008). Clark and Estigarribia (2011) found that when adults teach 3-year-olds new words, adults use gestures (as well as object manipulation) to indicate parts of a novel object and to describe actions and functions. McGregor and colleagues (2009) taught 2-year-old children the preposition term '*under*' through the modelling of objects, either with or without iconic gestures. Results showed that infants who had seen iconic gestures built a more robust and abstract representation of '*under*'. It has been suggested that iconic gestures may relieve cognitive load by making the meaning of a word more salient, leading to more efficient word learning (e.g. McGregor et al., 2009; Goldin-Meadow, 2000). However, as McGregor and colleagues' (2009) study used only one gesture condition, it remains unclear if gesture simply benefited learning by making the task more interactive and engaging. Research has also shown that 3-year-old children can use information from iconic gestures to map a novel verb to a novel scene (Goodrich & Kam, 2009). The scenes used in the Goodrich and Kam's (2009) study, however, were complex, involving different toys and actions, and children were not required to generalise the novel verbs to novel situations. It remains unclear, therefore, if children can use iconic gestures to zero-in on a particular aspect within a scene as the referent of novel verbs, which allows them to correctly generalise the verbs to novel situations. In other words, it remains unclear whether iconic gestures can help children solve Quine's (1960) problem, with respect to verb learning.

Current Study

The current study investigated the hypothesis that iconic gestures help children map a novel word to a particular feature within a novel complex scene, and therefore generalise the verb based on this feature. Around 26 months, children begin to demonstrate some understanding of iconic gestures (Namy, 2008; Namy, Campbell & Tomasello, 2004). Therefore, the current study tested 3-year-old children. We taught children ambiguous novel verbs, where the referent of the novel verb could be the action in the video (manner verb interpretation) or the end state (change-of-state verb interpretation). Teaching was accompanied by iconic gestures highlighting the manner, the end state or by no gestures. Children were then asked to generalise the novel verb to a scene in which either the end state was constant but the manner was novel, or the manner was constant and the end state was changed. The children were asked to point to one of the two scenes, presented side-by-side on the computer screen. We predicted that children's interpretation of ambiguous novel verbs should align with information encoded in gestures. That is, gesture can facilitate word learning because gesture guides children's attention to a specific aspect of a complex scene, which is the intended referent of the word.

Method

Participants

The study included 120 3-year-old children (57 females and 63 males) between the ages of 36 and 47 months (M= 41.48 months, SD= 3.13). Participants were recruited from nurseries in Warwickshire, England, and received a sticker in return for their participation. Testing took place in a quiet area of their nursery. Participants were pseudo-randomly assigned into one of three gesture conditions (manner gesture, end state gesture or no gesture). This was such that children were assigned into a group before the experimenter met them, for example working down an attendance list or the order in which consent forms were given to the experimenter, whilst taking care to balance groups, (e.g. in terms of sex). There were no significant differences in age (measured in months) between the gesture groups. Six of the children were acquiring at least two languages (end state gesture group: 2 children; manner gesture group: 1 child; no gesture group: 3 children). Although information about socio-economic status (SES) was not taken, the gesture groups were equally represented within each nursery in order to control for influences of SES.

Nineteen children were excluded from the analysis: one for attentional problems, and 18 for a side bias (all responses selected videos on one side). This left the following number of participants in each group: end state gesture group- 32, manner gesture group- 36, and no gesture group- 33.

Materials

Video clips

The study used 20 short video clips (8-11seconds) as exemplars of novel verbs. The videos all depicted an actor's hand manipulating objects in different ways to bring about a clear end state (e.g. placing sections of black material to create a 'cloud' shape on a white background). See Appendix 4 for details of all of the video clips.

The video clips were organised into five video groups. Within each group, the materials manipulated by the actions were the same. Each group consisted of two different manners, each resulting in two different end states. This resulted in four videos per group. For example, one video group consisted of the following four videos: Video 1) placing sections of material to create a 'cloud' shape, Video 2) placing sections of material to create horizontal stripes, Video 3) pushing sections of material using the index finger to create a 'cloud' shape, Video 4) pushing sections of material using the index finger to create horizontal stripes. Each child was tested on each of the five video groups once. Thus, there were five trials in total. As an example, when Video 1 from a given video group was used as the training video for a given child, then, at test, Video 2 was the same-manner video and Video 3 was the same-end-state video (both from the same video group). Video 4 would not be presented to this child. The video used for training was counterbalanced across participants, such that all videos appeared equally often as the training video, and as the same-manner and same-end-state videos at test. Further, the video groups were presented in a rotated order, such that across participants all video groups appeared equally often in the 1st, 2nd, 3rd, 4th and final trial.

The five novel verbs used in the study were *Dax*, *Larp*, *Stum*, *Tood* and *Blick.* These were randomised such that one verb did not always accompany one particular video group.

Iconic gestures

There were two types of iconic gestures: manner and end state. Manner gestures depicted the manner shown in the video and, therefore, depicted the action of the hand in the video, regardless of the state that action brought about. End state gestures depicted the shape or lines formed in the video, regardless of how that state was brought about. All gestures were produced live by the experimenter (See Appendix 5 for details of the gestures used).

Stimuli pre-test

A pre-test was conducted to ensure that children could match the iconic gestures to their referents in a two-way forced choice task (full details in Appendix 6). Fourteen 3-year-olds (7 females, M = 40.94months, SD = 3.28) who did not take part in the main experiment, matched the iconic gestures to the correct video above chance (.5), (the proportion of trials with a correct choice: M = .660, SD = 0.145, t (13) = 4.137, p =.001). Finally, the results of a likelihood ratio test comparing two models (one with and one without gesture type as a fixed effect) found that children's performance did not significantly differ between end state and manner gestures (χ^2 (1) = 0.154, p>.1). See Appendix 6 for details.

Procedure

Stimuli were presented on a 20" screen linked to a computer. The study started with four practice trials, in which participants were asked to identify familiar objects from two static images. Practice trials were designed to familiarise children with pointing to the screen and to boost their confidence. As there was no practice of pointing to videos, participants were not primed to attend to a particular aspect of the video (e.g. end state or manner) before the experimental phase.

The study then moved on to the experimental phase, which consisted of five trials. Each experimental trial consisted of two stages: training and testing (see Figure 4.1). In the training phase participants saw a video clip of an actor performing the target action and heard the training sentence '*Look! She's (novel verb)-ing it!'* Both the video clip and the training sentence were then repeated. For children in the manner gesture group, as the experimenter said the training sentence, she also produced a gesture that depicted the manner seen in the video. For children in the end state gesture group, as the experimenter said the training sentence, she also produced a gesture that depicted the end state in the video. Children in the no iconic gesture condition just heard the sentence. The experimenter sat next to participants at about 45° so they could see the child and the videos. The experimenter always looked at the child as she produced the sentences/ gestures.

In the test phase participants saw two videos, side-by-side, playing simultaneously and looped. Participants were asked '*which one's (novel verb)-ing it?*' Participants were asked to point to their chosen video. One video showed a different manner resulting in the same end state. If children had a change-of-state bias they would select this video. The other video showed the same manner resulting in a different end state. If children had a manner interpretation they would select this video. The test phase was the same for all participants: it did not involve any iconic gestures. During the test phase, when the experimenter asked the test question to a participant, she looked at the participant and was careful not to give any eye gaze cues about the target.

At test, children sometimes tried to point to both videos. In these cases, children were reminded they could only pick one and the question was repeated. Children's final choice, indicated by a pointing gesture, was noted down by the experimenter. If children made a choice, this was always made clear by them using a pointing gesture, children never made a verbal choice. All choices were noted down in real time by the experimenter, the sessions were not recorded and, therefore, no reliability analysis was conducted.

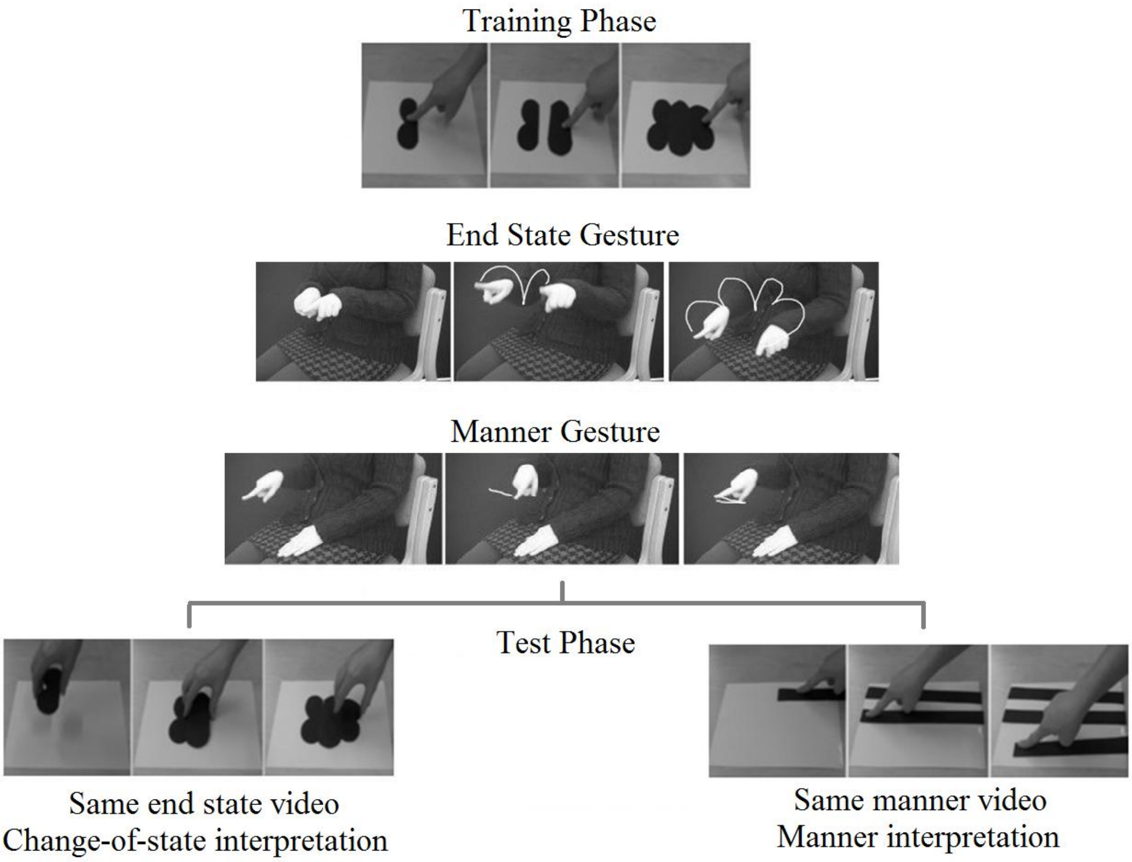


Figure 4.1. The structure of a single trial. The top photo represents the training video, the central photos depict the corresponding gestures performed live by the experimenter during training (the white line traces the path of the index fingers). The two bottom photos represent the two videos at test and the bottom photos The manner in the training video (top) uses a pointed hand shape and quick side-to-side movements to push shapes into position; the second manner in the left test video is slowly placing shapes down vertically.

Results

Two trials from two separate children (one per child) were removed as the children failed to make a choice.

Group Level Analysis

The dependent variable was binary, such that on any given trial, children could select the same manner video or not (i.e. select the same end state video). Therefore, the data was entered into a generalised linear mixed effects model. See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013).

Two models were compared to understand whether there was a main effect of gesture condition. The first model included the fixed effect of gesture condition (end state, manner or no gesture). The model also included random intercepts by participants. (Note that the random slope by participant for gesture condition was not included since gesture condition was a between participants manipulation). The second model only included a constant and random intercepts by participants.

The results from comparing the two models using a likelihood ratio test showed that there was a main effect of gesture (χ^2 (2) = 15.116, p=.001). Figure 4.2 shows the descriptive results obtained.

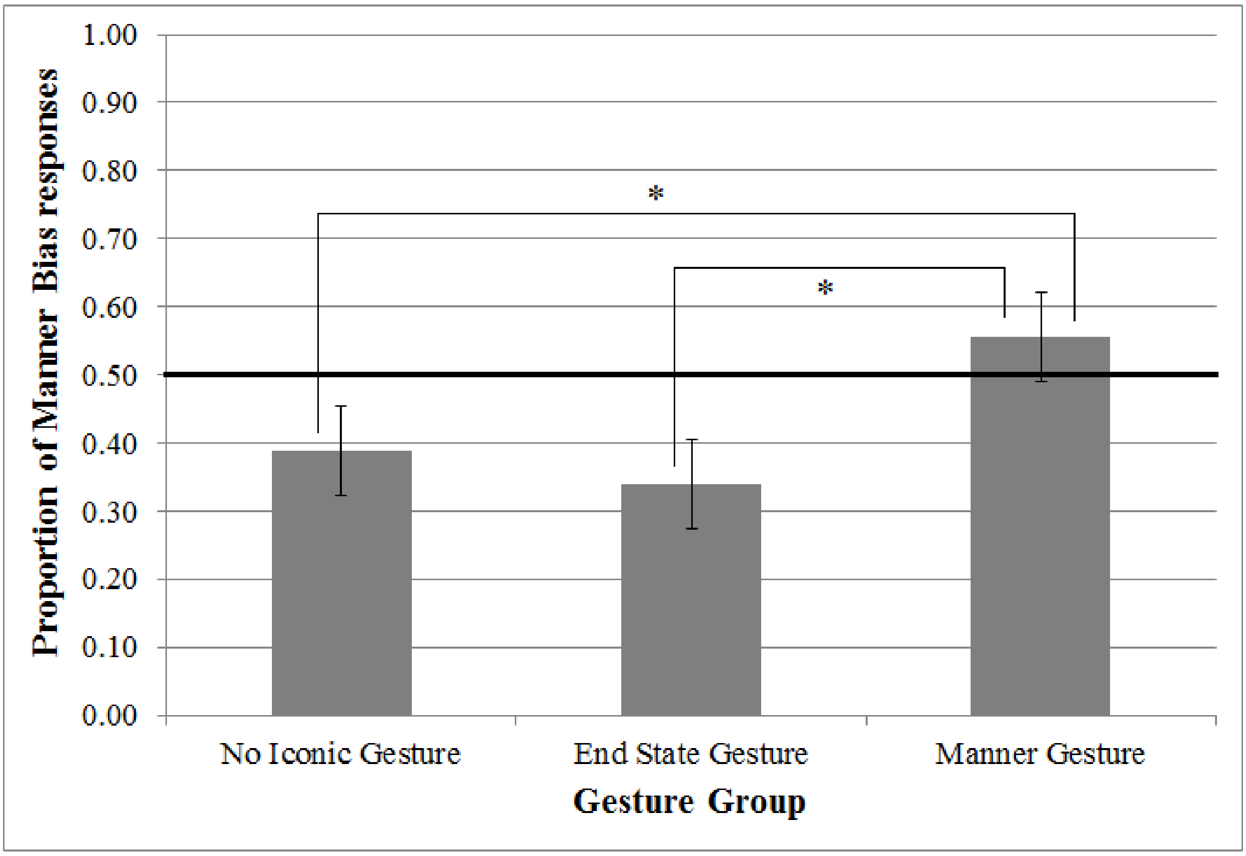


Figure 4.2. The mean proportion of trials in which the same-manner, different-end state videos were selected (i.e., generalisation of verbs based on manner) in the three gesture conditions. The error bars represent standard error of participant means. The thick line represents chance (0.5) and the * represents significance (p<.01)

In order to understand which gesture conditions were performing differently we looked more closely at the final model including gesture condition (Model 1). Table 4.1 reports the parameters of this model.

Table 4.1

Fixed effects of Model 1 (fixed effect of gesture condition)

	B	*SE*	*z*	*p*
Intercept	-0.689	0.181	-3.800	<.001
Gesture Condition- Manner	0.920	0.244	3.771	<.001
Gesture Condition – No gesture	0.225	0.251	0.896	0.370

Note, for the gesture manipulation, the end state gesture condition was taken as the reference group and the other gesture conditions were contrasted to this.

.

The model shows that there was a significant effect of gesture such that children in the manner gesture condition selected the same-manner videos more often than children in the end state gesture condition ($p<.001$). The model also showed that there was no effect of being in the no gesture condition as compared to the end state gesture condition ($p>.1$), such that the selected the same manner video equally often as each other.

In order to examine the effect of gesture between the no gesture and the manner gesture conditions the model was rerun using the manner gesture condition as the reference group (Model 2); contrasts were made between this group and the others. See Clopper (2013) for how to model multi-level factors using linear mixed effects models. Table 4.2 reports the parameters of this model.

Table 4.2

Fixed effects of Model 2 (fixed effect of gesture condition)

	B	*SE*	*z*	*p*
Intercept	0.231	0.163	1.416	0.157
Gesture Condition- End State gesture	-0.920	0.244	-3.771	<.001
Gesture Condition – No gesture	-0.695	0.238	-2.915	.004

Note, for the gesture manipulation, the manner gesture condition was taken as the reference group and the other gesture conditions were contrasted to this.

The model showed there was a significant effect of being in the no gesture condition as compared to the manner gesture condition, such that children in the manner gesture condition selected same manner videos more often (p=.004). As before, there was a main effect of gesture between the manner gesture group and the end state gesture group (p<.001).

Additional analysis requested by the editor of the journal Child Development, can be found in Appendix 7. None of these additional analyses alter the key findings.

Comparison to chance

Then, the children's performance was compared to chance (.5). Children selected more change-of-state choices than chance when they saw either no gestures (t (32) = -2.633, p=.013) or end state gestures (t (31) = -3.978, p<.001). Children who saw manner gestures showed a trend towards more manner responses than chance, but this was not statistically significant (p>.1).

Individual Level Analysis

Given that children who saw manner gestures did not perform differently from chance, we investigated the possibility that seeing manner gestures simply led to confusion (and chance performance) rather than a shift towards a manner bias. To do this we looked at the number of children who showed a strong bias in their responses in the three conditions. Children were defined as having a strong bias if they picked the opposite interpretation only once or not at all throughout the experiment. For example, children were defined as change-of-state biased if they only chose the manner interpretation once or never. Children who did not fit into these categories were defined as having no strong bias.

Table 4.3.

The number of children in the three gesture conditions and in the three response bias groups.

Gesture Group	**Change-of-state Bias**	**No strong bias**	**Manner Bias**
End State	16	13	3
Manner	6	18	12
No Gesture	12	18	3

The gesture groups and their response bias were significantly associated ($\chi^2 = 13.925$, $df = 4$, p=.008). That is, children in different gesture groups showed different patterns of bias.

Next we tested if certain biases were more common in some gesture groups than others. To do this we reran the chi-squared analyses for each response category (see the columns in Table 4.3). This compared the observed frequency against the frequency expected if the gesture conditions did not have any impact on biases in response. We inferred the expected frequency based on the total number of children in the three gesture groups: manner gesture N = 36, end-state gesture N = 32, no gesture N = 33. If gesture groups did not have any impact on the biases, then we should expect that the number of children in the three gesture group should be at the ratio of 36:32:33, regardless of the bias groups. For example, the proportion of the manner gesture group was expected to be .356 = 36 / (36 + 32 + 33). Thus, for the strong manner bias group (N = 18), the expected frequency for the manner gesture group was 18 * .356

First, the group which demonstrated a strong manner biases showed a significant difference between the observed and expected frequencies (χ^2 = 7.55, *df* = 2, *p*=.023). This difference arose because that there were marginally more children than expected with a strong manner bias in the manner group and fewer than expected in the end state gesture group (χ^2 = 3.38, *df* = 1, *p*=.066) and in the no gesture group (χ^2 = 3.6, *df* = 1, *p*=.058).

Next, the group which demonstrated a strong change-of-state bias showed a marginally significant difference between the observed and expected frequencies (χ^2 = 5.7, *df* = 2, *p*=.058). This difference arose because there were more than expected children in the end state gesture group, and fewer than expected children in the manner group (χ^2 = 4.83, *df* = 1, *p*=.028). There were no significant differences when comparing manner and no gesture groups or end state and no gesture groups (*p*>.1 for both).

Finally, we investigated the group of children who did not show a strong bias. The results showed no significant effect (*p*>.1), such the comparable amount of children in each group had no strong bias.

Discussion

Overview of Study

This study investigated the effect of seeing an iconic co-speech gesture on 3-year-old children's ability to learn novel verbs. The results supported the hypothesis that information contained within these gestures can influence children's semantic representations of novel verbs. The results suggest that gestures could guide children's attention to a particular aspect of a complex scene as the referent of a novel verb. Children who saw iconic gestures depicting manner were more likely to generalise the verb to a new scene with the same action, compared to children who saw no gestures or end state gestures. Children showed a baseline bias (in the no gesture group) towards the end-state interpretation; thus, children who saw manner gestures as a group selected the manner interpretation only at a chance level. This may raise a concern that children in the manner gesture group were simply confused; however, further analysis that classified children based on the bias in their responses did not support this alternative interpretation. Confused children should respond randomly, without any strong manner or change-of-state bias. If manner gestures had confused children, then the children in the manner gesture group should have been over-represented among the children with no strong bias; however, the three gesture groups were equally represented. Moreover, gesturally encoded information led to a higher number of children with a strong bias for the encoded information. That is, among the children with a strong manner bias, the children in the manner gesture group were over-represented, in comparison to those in the no-gesture group and the end-state gesture group. Among the children with a strong end-state bias, children in the end-state gesture condition were over-represented, in comparison to those in the manner-gesture condition. This pattern of results suggests that children in the manner gesture group were more likely to take the action, not the change-of-state, as the critical feature of the complex scene in the video. Thus, we conclude that utilising information contained in iconic co-speech gestures is one way that children can zero-in on a particular aspect of a novel scene as the referent of a novel verb.

Iconic Gestures and Word Learning

The current finding is compatible with other studies that have found that iconic gestures can help children to learn new words (e.g. the preposition '*under*': McGregor et al., 2009; verbs: Goodrich & Kam, 2009; nouns in a second language: Tellier, 2008). The current study, however, extends the literature by clarifying *how* gestures can aid learning. McGregor and colleagues (2009) found that children in the iconic gesture condition performed better in a word learning task; however, it was unclear if that was because gesture simply increased overall interactivity or engagement in the task. The current results cannot be accounted for by increased overall interactivity or engagement as different gestures had different effects; children were guided by specific information contained in gesture. In addition, although Goodrich and Kam (2009) found that children could use iconic gestures to link a novel verb to a novel scene, it remained unclear what children believed the novel verb referred to exactly, as they were not required to generalise verbs to novel scenes. The current study found that seeing iconic gestures can help children to focus on a particular referent within a complex scene when learning novel verbs, rather than simply associating a verb with the scene in general. The current study has, therefore extended the previous literature in two ways. Firstly, as different gestures influenced children's verb learning differently, that is the gestural content is important, gestures do more than just make the learning environment more engaging. Secondly, gestures can help to select a particular aspect within a complex scene as the referent of a novel verb, which is crucial for generalizing the verb to new situations; gestures do not simply help children to associate a word with a scene in general. That is, using information in iconic gestures may be one way by which children can solve which feature of a scene, a verb is encoding (e.g. Quine, 1960; Gentner, 1982, Gleitman & Gleitman, 1992).

How do iconic gestures help children zero-in on the referent in a complex scene? Gesture is a schematic representation that abstracts away irrelevant aspects of complex scenes. Thus, seeing an iconic gesture along with a complex scene helped children pinpoint the relevant information within the complex scene. In other words, iconic gestures help overcome some of the key difficulties of verb learning; extracting relevant features of a scene and packaging them into a conceptual unit (Gentner, 1982). Iconic gestures may serve a similar function to seeing multiple complex scenes that repeat the referent. Gentner and colleagues have shown that children and adults can compare information across exemplars in a domain-general way and align features of one scene with another (Gentner & Markam, 1997). Importantly, these comparisons can be used to highlight the structural relation that exemplars have in common, and take the focus away from the actual objects of any exemplar (Gentner & Markman, 1997). Childers (2011) has argued that children can use this type of comparison to help acquire novel verbs. Specifically, Childers (2011) showed that when learning a novel verb that can be interpreted either as a manner or a change-of-state verb in the initial exposure, two-and-half year-olds could zero-in on the referent after seeing additional complex scenes in which the referent (e.g., either the same manner or the same end-state) remained constant. In this situation, children could compare multiple complex scenes and find the common feature, which is likely to be the referent. The comparison of an iconic gesture and the complex scene may bring similar benefits to word learning, but in a more efficient way: exposure to one scene already enables comparison, and the schematic nature of gestural representation makes it easier to find common features. In other words, iconic gestures provide a sketch of abstract semantic representations of verbs, which help children carry out fast mapping (Carey & Bartlett, 1978) of newly encountered verbs and correctly apply the verbs to novel complex scenes later.

Different Types of Iconic Gestures

It is interesting that seeing manner gestures had a large effect on verb learning but end state gestures did not. There are at least three potential explanations for this finding. Firstly, this pattern may reflect a floor effect, as children who saw no gestures showed an end-state interpretation bias, that is interpreting the novel verb as a change-of-state verb. Seeing end state gestures could not increase this bias, while seeing manner gestures had more room to influence interpretations.

The other two accounts suggested here reflect the idea that some types of iconic gestures may have more of an influence than others on word learning. These are both speculative and further work would be needed to distinguish these accounts. Firstly, gestures may have a larger influence on word learning when the information contained is not compatible with children's natural bias (in this case their natural bias was a change-of-state interpretation). When children see a gesture, which is compatible with their own bias, they may pay little attention to it, as it is only confirming their original understanding. When a gesture contains information incongruent with their natural bias, however, children may pay more attention to it, as this suggests that their original interpretation of the novel word is incorrect. Research has shown that gestures are produced more often when it is potentially more difficult for the listener to comprehend the concurrent speech. For example, adults produce more iconic gestures when they utter an unexpected word (Beattie & Shovelton, 2000). Similarly, 4-year-old children often use iconic gestures to clarify ambiguous concurrent words (Kidd & Holler, 2009). In terms of comprehension, Holle and Gunter's (Experiment 3, 2007) study with adult participants found that gestures boost the activation levels of a subordinate meaning of a homonym, but had little influence on the dominant interpretation of the word. This suggests that, for adults at least, gestures may have more impact when concurrent words should be interpreted against the natural bias for interpretations.

Secondly, the manner and end-state gestures in this study were iconic in different ways and this difference may have led to end state gestures having less influence than manner gestures. We know from the pre-test that there was no difference in children's ability to match the two gesture types to their referents, but there may still be a difference in how well children are able to use them during verb learning. In line with this account is research by O'Reilly (1995), who found that children were able to comprehend gestures where the hand represented an object, better than those where the hand acted as if holding an imaginary object. It appears that children struggle when they must imagine features of the scene being depicted. In the current study, although there was some imagery required for the manner gestures (e.g. the hand holding or manipulating imaginary materials), the end state gestures arguably required more imagination, for example, the shape outline being traced by the index fingers. This line must have been imagined and remembered in order to understand the referent (e.g. a '*cloud*' shape). Although the pre-test revealed children could map the gestures to their video referents, it may have been too cognitively demanding to then use this information during verb learning. It would be an interesting topic for future research to investigate more specifically which types of iconic gestures can influence word learning. It would also be interested to investigate whether iconic gestures can help children to focus on aspects, such as manner, at the expense of other features, such as actors and objects.

Children's Natural Bias

It is interesting to note that children in the current study who saw no gestures tended to interpret the novel verbs as change-of-state verbs, though the natural bias for children's interpretation was not the focus of this study. There is some debate in the literature regarding children's natural biases when learning words that can be either manner verbs or change-of-state verbs. Some studies have found that children often interpret such words as manner verbs (e.g. Forbes & Farrar, 1995), while others have found children to interpret them as change-of-state verbs (e.g. Behrend, 1990). It is an important topic of future study to investigate what features of stimuli and tasks influence the direction of the bias.

General Conclusions

Iconic gestures highlight particular features within a scene and guide children's semantic interpretation of novel words towards the gesturally encoded features. Such gestures may be one of the important contextual cues that children take advantage of in real-life word learning situations. The result also suggests that iconic gesture is a potentially useful tool for teaching new words to children in educational or clinical settings.

PART II

RIGHT-HANDED POINTING AND VOCABULARY DEVERLOPMENT

‘There was speech in their dumbness,

language in their very gesture’

-*Shakespeare, The Winter’s Tale, Act. 5, Scene 2*

CHAPTER 5

LITERATURE REVIEW II

The brain is organised such that different regions become specialised for different processes. Some of these processes are more dominant in the left hemisphere, and others in the right. This review chapter focuses on the clearest cases of this type of laterality and how they are associated with one another, namely the left lateralisation of language and gesture and the right-hand bias found in most individuals.

5.1

MANUAL HANDEDNESS

Development

When talking about handedness, most people are referring to manual handedness. That is, they are referring to the hand with which they typically prefer to complete tasks, such as writing, throwing a ball etc. Around 89% of adults are right-handed (Gilbert & Wysocki, 1992). There is, however, some debate about the development of manual handedness. For example, McManus and colleagues (1988) found that by the age of three, the direction of children's handedness was fairly fixed, although the degree of handedness increases until around 7 years old. In contrast, some researchers argue that manual handedness can be observed very early in development. For example, manual handedness at 10-12 years is associated with prenatal thumb sucking preferences (Hepper, Wells & Lynch, 2005). Further, other research has suggested that on a grasping task infant handedness remains relatively stable between 7-13 months (Michel, Tyler, Ferre & Sheu, 2006). This thesis does not address the issue of manual handedness development, but it is useful to know that some indication of manual handedness can be found in infancy, while at 3-years it can be assessed more reliably.

The task used to assess handedness can have a large impact on manual handedness reliability. In particular, bimanual tasks appear to provide a more stable assessment for handedness than uni-manual tasks. For example, in a simple grasping task, although infants as young as 6-12 months demonstrated an overall right-hand bias, 61% of these individuals did not use one hand consistently (Fagard & Lockman, 2005). Between 30-36 and 48 months children's hand choice became a lot more stable in this type of task. This age range is consistent with McManus and colleagues' (1988) finding that around 3-year-old children's direction of manual handedness is fairly fixed when tested on a range of uni and bimanual tasks. In contrast, when 6-12-month-olds were given a bimanual task, to assess a dominant hand, only 36% of these individuals did not use one hand consistently (Fagard & Lockman, 2005). The bimanual task also showed that a right-hand over left-hand bias at a population level could be seen descriptively at 6-12 months and the difference became significant at 18-24 months. The study in chapter 8 of the current thesis tests the manual handedness of 3-year-old children. As a result of reviewing the literature, this study will use a uni-manual (drawing task) and bimanual task (unscrewing a lid) to assess handedness. These tasks should give a reliable test of handedness, at an age when handedness is fairly fixed.

Finally, it should be noted that males are more likely to be left-handed than females (see Papadatou-Pastouo, Martin, Munafo & Jones, 2008, for a meta-analysis). Although Papadatou-Pastouo and colleagues' (2008) meta-analysis was restricted to adults over 16 years, there is also evidence of a similar sex difference in children (e.g. Leask & Beaton, 2007).

Manual handedness and gesture/ sign handedness

There is some evidence of a relationship between manual and gesture handedness. Gesture handedness is the hand that individuals typically prefer to use to gesture with while speaking. For example, Vauclair and Imbault (2009) found a significant correlation between hand preference and pointing, in 10 to 40-month-old children (although manual handedness only explained 15% of the variability in pointing handedness). Similarly, Bonvillian and colleagues (1997) found that the dominant hand for signing, in young infants acquiring American Sign Language as a first language, was a strong indicator of their manual handedness.

Other studies, however, have not found an association between manual and gesture handedness (14 months: Esseily, Jacquet & Fagard, 2011; 15-30 months: Cochet, & Vauclair, 2010). Further, of the studies that have found an association, gestures and signs often seem to show a larger right bias than manual handedness. For example, in Vauclair and Imbault's (2009) study of 10 to 40-month-olds, 73% of individuals who showed clear manual handedness were right-handed, whereas 88% of individuals who showed clear pointing handedness were right-handed. Further, 36% of individuals who were left-handed for object manipulation were right-handed for pointing, whereas only 3% individuals who were right-handed for object manipulation were left-handed for pointing (78% remained right-handed). In addition, while 53% of individuals who were ambidextrous for object manipulation were right-handed for pointing, only 10% of individuals who were ambidextrous for object manipulation were left-handed for pointing. Similarly, between 14 and 20 months, infants show a stronger right-hand bias when pointing declaratively, than when grasping objects (Jacquet, Esseily, Rider & Fagard, 2012). Finally, the young deaf infants (ranging from 5- 46 months at testing) in Bonvillian and colleagues' study (1997) showed a stronger right-hand bias for signs than for manual activities.

The stronger right-hand bias for gesturing (and signing), as compared to non-communicative manual activities, may be due to the relationship between gesturing and language in the left hemisphere. This is discussed further in section 5.4.

5.2

LATERALISATION OF LANGUAGE

Some of the earliest work on language localisation in the brain came from lesion patients. Broca (1861) and Wernicke (1874) both described patients who had left sided brain lesions which had resulted in the impairment of their language abilities. Now a huge amount of research has been conducted in this area.

Broca's area has now been localised to the left inferior frontal gyrus (e.g. Cabeza & Nyberg, 2000), while Wernicke's area has been localised to the left superior temporal gyrus (e.g. Cabeza & Nyberg, 2000). Traditionally, Broca's area has been thought to be critical for speech production, while Wernicke's area was thought to be more involved in speech comprehension, since there is some degree of a double dissociation between lesion sites and these two abilities (e.g. Geschwind, 1970). More recent literature indicates, however, that the picture is far more complicated, for example, Broca's area has also been shown to be involved in speech perception as well as production (Price, Wise, Warburton, Moore, Howard, Patterson et al., 1996). Further, evidence from patients with damage to these areas, suggest that Broca's area may be more involved in syntactic processing, while Wernicke's area might be more involved in semantics (e.g. Kean, 1977). This is discussed further in section 5.4. Finally, it also seems that Broca's area is critically involved in the semantic integration of information (e.g. Willems, Özyürek & Hagoort, 2007). This again will be revisited in section 5.4., when we consider how gesture and language interact in the left hemisphere.

It is clear that many areas are involved in the processing of language. For example, Binder and colleagues (1997) conducted a functional magnetic resonance imaging (fMRI) study and found that many areas outside of Broca's and Wernicke's area were activated during phonetic and semantic analysis of single words. These left lateralised areas included the lateral and ventral temporal lobes (including the superior temporal sulcus), prefrontal areas (including the superior and inferior frontal gyri), the angular gyrus and the perisplenial region (Binder, Frost, Hammeke, Cox, Rao & Prieto, 1997).

It should be noted that although the left hemisphere is typically dominant in linguistic processes, the right hemisphere is also involved in general language processes (e.g. Taylor & Regard, 2003). Further, the right hemisphere has important involvement in specific aspects of language processing. For example, understanding the moral content of a story is related to higher activation in the right temporal and prefrontal cortices (Nichelli, Grafman, Pietrini, Clark, Lee & Miletich, 1995). Similarly, the right hemisphere plays a more dominant role in the processing of metaphors (e.g. Taylor & Regard, 2003). Finally, the right hemisphere, specifically the inferior frontal lobe, is typically involved in the processing of emotional prosody when listening to speech (Buchanan, Lutz, Mirzazade, Specht, Shah, Zilles et al., 2000).

As well as imaging studies, the left hemisphere's dominance in language processing can also be seen behaviourally. For example, Kimura (1973a, 1973b) used dichotic listening to assess language dominance, with a right-ear advantage thought to show left-hemisphere dominance. Mouth asymmetries are another behavioural measure thought to demonstrate language lateralisation. For example, Graves and colleagues (1982) found that most people (males and females, left- and right-handers) opened their mouth to a larger extent on the right side of the mouth. This was thought to reflect the left hemisphere's dominance in speech production and in controlling the right half of the face (Graves, Goodglass & Landis, 1982). Further, adults make more errors in speech detection when they can only see the speaker's left side of the mouth, compared to their right side (Nicholls & Searle, 2006). This suggests that the right side of the mouth (controlled by the left hemisphere) is more visually expressive, and useful for listeners (Nicholls & Searle, 2006).

The right-side bias in mouth symmetry does seem to be related to language dominance, since people do not always show this bias. For example, in the expression of emotions, there is a left-side bias of the expressiveness of the face and mouth (Borod, Haywood & Koff, 1997). Further, it has been suggested that the right-side bias can be attenuated in speech when metaphors are being used, which are lateralised to the right hemisphere (Argyriou and Kita, 2013). As we have seen both emotion (Buchanan et al, 2000) and metaphor processing (Taylor & Regard, 2003) are both associated with the right hemisphere, which can explain the left side mouth asymmetry.

As with the research on manual handedness, there appear to be some sex differences in language laterality patterns. For example, results from a dichotic listening task showed that males had a small but significant right-ear advantage over females (Lake & Bryden, 1976). This suggests that males have stronger laterality patterns than females. This increased left-hemisphere bias for language in males appears to be in contrast to the increase in left handedness in males (e.g. Papadatou-Pastouo, Martin, Munafo & Jones, 2008). It is not clear why this should occur. There is, however, some debate about sex differences in cerebral asymmetry at a population level (e.g. Sommer, Aleman, Bouma & Kahn, 2004). For example, a large fMRI study revealed no differences between the sexes in cerebral organisation of language processing (Frost, Binder, Springer, Hammeke, Bellgowan, Pao et al., 1999). Further, a meta-analysis of fMRI studies found no evidence for more bilateral processing patterns of language in females (Sommer et al., 2004). Finally, Lake and Bryden (1976) note themselves that the sex differences they found may have reflected different strategies males and females employed to complete the dichotic listening task.

The lateralisation of language has also been investigated in infants. For example, Holowka and Petitto (2002) found that infants in the first year of life show a right biased asymmetry of the mouth while babbling, suggesting that the left hemisphere is more involved in producing these early vocalisations. They also found a left biased asymmetry for smiling suggesting infants do not just have a tendency to open their mouth wider on the right side (Holowka & Petitto, 2002). Similarly, an fMRI study with 3-month-olds found that even at this very young age, the left hemisphere was showing signs of dominance during speech perception (Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002).

Previous research has also focused on the relationship between vocabulary development and language lateralisation. For example, Paulesu, and colleagues (2009) found that the left hemisphere (including Broca's area, the left supramarginal gyrus at the temporoparietal junction, and the cerebellum) was particularly active while adults acquired new words. In terms of infants, event-related potential (ERP) studies suggest that vocabulary development is associated with cerebral reorganisation and a shift towards left-hemispheric dominance (Mills, Conboy & Paton, 2005). For example, at 13 and 17 months old, although infants show some differential activation to known and unknown words, this is displayed bilaterally across both hemispheres (Mills, Coffey-Corina & Neville, 1997). In contrast, at 20 months old, the temporal and parietal cortices in the left hemisphere are shown to respond differently for known words, compared to unknown or backwards words (Mills, Coffey-Corina & Neville, 1993). This suggests that as children acquire new words, the left hemisphere begins to take a more dominant role in processing language. In order to understand whether it is general maturation or vocabulary development, Mills and colleagues (2005) tested 20-month-old typical developing infants and 28-30-month-old late talkers and found that they showed the same developmental pattern seen in earlier studies. Specifically, infants' responses to words became more left lateralised as their vocabulary increased. Finally, Mills and colleagues (2005) studied 20-22-month-old bilingual infants with a dominant language and found that the P100 component of the ERP was greater in the left hemisphere when children who produced a lot of words listened to their dominant language, but was bilateral when they listened to their non-dominant language. In contrast, children who did not produce many words showed bilateral patterns for both their dominant and non-dominant languages (Mills et al., 2005). These studies provide good evidence that vocabulary development and left lateralised language are associated in development. This relationship is important to the current thesis. Chapter 6 investigates how right-handed gestures, which may be related to left language lateralisation, are associated to receptive vocabulary development at the onset of referential communication. Further, Chapters 7 and 8 investigate the use of the right hand for gesturing and vocabulary development in 3-year-old children.

Neuroimaging studies have revealed that the left lateralisation of language is true for most individuals (e.g. adults: Knecht, Drager, Deppe, Bobe, Lohmann, Floel et al., 2000; children: Szaflarski, Rajagopal, Altaye, Byars, Jacola, Schmithorst, et al., 2012). This appears to be true for the vast majority of right-handed individuals (Knecht et al., 2000). This pattern is weaker in left-handed individuals, but still a majority of left-handed individuals show left lateralisation of language (adults: Knecht et al., 2000, children: Szaflarski et al., 2012). Given that only around 11% of the population are left-handed (Gilbert & Wysocki, 1992), the current thesis will assume that language is left lateralised in a large majority of the participants studied.

5.3

LATERALISATION OF GESTURE

Comprehension

The processing of seeing someone else gesture has been found to be lateralised to the left hemisphere. For example, a positron emission tomography (PET) imaging study found that the left hemisphere was more activated when processing meaningful hand actions (e.g. pantomiming sewing a button), compared to meaningless actions (Decety, Grezes, Costes, Perani, Jeannerod, Procyk et al., 1997). In particular the left-hemisphere regions involved were the inferior frontal gyrus (Broca's area) and middle temporal gyrus (Decety et al., 1997). In contrast, the right hemisphere was more dominant in processing meaningless movements (Decety et al., 1997). Similarly, another study found that the left parietal cortex was more activated when viewing dots which represented the goal directed action of a hand (e.g. drinking), compared to seeing dots representing expressive dance-like whole body movements (Bonda, Petrides, Ostry & Evans, 1996). These studies suggest that the content of hand movements influences how those movements are processed, and in particular the processing of meaningful gestures appears to be lateralised to the left hemisphere.

The lateralisation of pointing comprehension has been studied in infants as young as 8 months. Even at this young age, the posterior temporal cortex appears to be processing gestures in a similar way to adults (Gredebäck, Melinder & Daum, 2010). Specifically, activation in this area was modulated by whether a pointing hand was congruent with the location of a previous target or incongruent. However, whereas incongruent over congruent trials elicited a larger N200 component in the left hemisphere for adults, incongruent trials elicited a larger P400 component in the right hemisphere for 8-month-old infants. This suggests that although similar areas are already involved in gesture perception and comprehension at 8-months, maturation is still needed to achieve adult-like patterns (Gredebäck et al., 2010).

In a similar way to which the content of speech can influence the neural areas involved (e.g. Nichelli, Grafman, Pietrini, Clark, Lee & Miletich, 1995), the content of gestures can influence the neural processing of those gestures. For example, Gallagher and Frith (2004) found that observing gestures which expressed inner states (e.g. '*I am angry*'/ '*I like it*') was associated with bilateral activity including the amgydala and the temporal poles. The comprehension of these gestures was also associated with activation in the right superior temporal sulcus. This may not be surprising given the right hemisphere's dominance in the processing of emotions (e.g. Schwartz, Davidson & Maer, 1975; Esslen, Pascual-Marqui, Hell, Kochi & Lehmann, 2004) and emotional tone as outlined in section 5.2 (Buchanan, Lutz, Mirzazade, Specht, Shah, Zilles et al., 2000). In contrast, the study showed that gestures which communicated demands (e.g. '*sit down*'/ '*hurry up*') were associated with the areas usually associated with language processing in the left hemisphere, including Broca's area (Gallagher & Frith, 2004).

Production

Imaging studies have facilitated a greater understanding about where in the brain processes occur when people produce hand actions. Imaging has shown that the left hemisphere is more dominant in simple motor tasks. For example, Kim and colleagues (1993) found that while the right motor cortex was only activated during the movement of the left hand (fingers and thumb touching), the left motor cortex was activated during movement in either hand.

This left-hemisphere dominance of actions, however, is not restricted to simple motor tasks and also extends to production of gestures. For example, healthy adults were asked to pantomime actions associated with a range of tools (while other were asked to imagine the real actions) (Moll, de Oliveira-Souza, Passman, Cunha, Souza-Lima, & Andreiuolo, 2000). The fMRI results revealed that the left hemisphere was more activated than the right, regardless of which hand was used to perform the action (for both pantomimed and imagined actions). More specifically, the left intraparietal cortex was thought to be involved in representing tool associated actions (Moll et al., 2000). In another experiment, participants were asked to pantomime (without tools) transitive actions made with a tool (e.g. pantomime how to sew) and familiar gestures that do not represent an action with a tool (e.g. beckoning someone) (Kroliczak & Frey, 2009). The results showed that both types of gestures activated the left hemisphere, (specifically the parietal and premotor cortices) more than the right regardless of hand choice (Kroliczak & Frey, 2009).

As well as imaging studies, the hemisphere that is dominant in producing an action can be inferred by which side of the body the action is executed. This is because in the brain, movements are processed in the contra-lateral hemisphere; for example, the left hemisphere controls the right half of the body (See Cincotta & Ziemann, 2008, for a review of uni-manual actions). It thus follows that when the left hemisphere is dominant in producing a gesture, this can be observed in the right hand and arm. Conversely, when the right hemisphere is dominant in producing a gesture, this can be observed in the left hand and arm.

When speaking, right-handed adults show a right-hand bias for gesturing but not for self- touch (Dalby, Gibson, Grossi & Schneider, 1980), (but see Hatta & Dimond, 1984, who failed to find any hand differences in self touch by Japanese people). Although this is clear for right-handers (e.g. Dalby et al., 1980; Kimura, 1973a), it has been found that left-handers (with left lateralised language) produce more right-handed gestures than you would expect based on their manual handedness patterns alone (e.g. Kimura, 1973b). The relationship between gesture handedness and language in considered further in 5.4. This suggests that the left hemisphere is dominant in the production of such gestures, consistent with neuro-imaging studies already mentioned.

Brain lesion studies

Patients who have had their corpus callosum severed (so called '*split-brain*' patients) are valuable in understanding the lateralisation of gestures. Kita and Lausberg (2008) found that patients, who had language production capabilities only in their left hemisphere, produced iconic gestures containing spatial content with both hands; however, left-handed gestures were less tightly synchronised to speech than right-handed gestures. This suggests that the language production and gesture production are not completed tied together, and the right hemisphere has the ability to produce gestures even without the ability to produce speech.

Differences in gesture handedness after brain lesion also show that gesture types are not all processed in the same way (Lausberg, Zaidel, Cruz & Ptito, 2007). For example, Lausberg and colleagues (2007) found that split-brain patients had a preference in favour of their left hand for beat gestures and shrugs, and a right-hand preference for pantomime gestures. The authors argued that the left-hand preference for some gestures reflects the right hemisphere's specialization to process emotional content (Lausberg, et al., 2007).

Other studies have investigated the relationship between lateralised brain lesions and ideomotor apraxia (difficulty in sequencing and producing tool-use pantomimes and communicative gestures) (Wheaton & Hallett, 2007)[2]. In particular, left-hemispheric damage is thought to be more likely to result in limb apraxia than right-hemispheric damage (e.g. Wheaton & Hallett, 2007). For example, Haaland and colleagues (2000) tested 78 stroke patients: 41 with left-hemisphere damage and 37 with right-hemisphere damage. Patients completed a gesture imitation task and were described as having ideomotor limb apraxia if their performance was sufficiently impaired (in terms of location, hand orientation etc.). The results showed that only 8% of the right-hemisphere damaged patients were classified as having apraxia, in contrast to 41% of the left-hemisphere damaged patients (Haaland, Harrington & Knight, 2000). This suggests that the left hemisphere may play an important role in the planning and execution of semantic motor actions. The study then compared the lesions of the left-hemisphere damaged patients who had and did not have apraxia. The results showed that the left middle frontal gyrus and the inferior and superior parietal cortex were most likely to cause apraxia compared to other regions (Haaland et al., 2000).

Finally, as well as causing damage to gesture production, left-hemispheric lesions are also more likely to cause gesture comprehension problems (Bickerton, Riddoch, Samson, Balani, Mistry & Humphreys, 2012). A recent review of apraxia assessment techniques found that gesture comprehension tasks (as well as pantomime production) could reliably identify whether patients had a left or right sided lesion, whereas imitation and actual object use tasks could not (Bickerton et al., 2012).

Taken together from a range of studies (imaging, behavioural, patient), it seems that the parietal and the frontal regions are most involved in the processing of gestures and meaningful movements, and this is also lateralised to the left hemisphere.

---

[2] It should be noted that the assessment and classification of different apraxia types is currently too simplistic, and further research is needed to accurately identify all of the possible patterns of impairments (See Cubelli, Marchetti, Boscolo & Della Sala, 2000). The current review does not include this debate as it is not relevant to the current thesis.

5.4.

LANGUAGE AND GESTURE IN THE BRAIN

As we have seen in section 2.3, there is a lot of support for the idea that the language and gesture system are tightly linked and coordinated (McNeill, 1985). For example, Bernardis and Gentilucci (2006) found that producing gestures, which were semantically related to the concurrent words, altered adults' production of words, but meaningless arm movements did not. Further, producing a semantically related word influences the production of gestures, while the production of pseudo words did not (Bernardis & Gentilucci, 2006).

Neuro-physiological studies also support this idea. For example, Kelly and colleagues (2004) measured ERPs when adults watched videos containing semantically matching and mismatching speech gesture combinations. The study found an early influence of the semantic congruency on ERPs, indicating that gestures affected the acoustic processing of speech, and late influences on ERPs suggesting a role for gestures in semantic processes (Kelly, Kravitz & Hopkins, 2004). Further, research has shown that both the N300 and N400 potentials are reduced when participants view picture probes that were previously described by videos including speech and gesture, compared to when the videos contained speech alone (Wu & Coulson, 2007). This suggests that iconic gestures can help listeners to build a visuo-spatial representation of verbal speech (Wu & Coulson, 2007).

Neuro-imaging studies have also found evidence for a neural overlap between speech and gesture (e.g. Xu, Gannon, Emmorey, Smith, Braun, 2009). For example, Willems and colleagues (2007) found that activation in the left inferior frontal cortex (Broca's area) increased more when seeing mismatching speech and gesture combinations, than when seeing matching combinations. This suggests that the integration of semantic information in Broca's area is not specific to language and can include information from different modalities. Similarly, Skipper and colleagues (2007) found that the presence or absence of semantically congruent co-speech gestures can modulate activation in Broca's area, such that when gestures are present, activation decreases. The authors suggest that this is because the gestures provide additional semantic information and so there is less ambiguity to deal with (Skipper, Goldin-Meadow, Nusbaum & Small, 2007). These studies show that speech and gesture are semantically integrated at complex, neural levels, possibly occurring at Broca's area.

It should be noted that not all studies have found Broca's area to be key in speech-gesture integration. For example, Holle and colleagues (2010) only found that the left inferior frontal gyrus was activated during integration after the threshold for activation had been lowered. The study did show, however, that the left hemisphere (specifically superior temporal gyrus region) becomes more active when speech is noisy, and more reliance on gestural input is required to comprehend the utterance (Holle, Obleser, Rueschemeyer & Gunter, 2010).

It should also be noted that not all types of gestures are integrated with speech in the same way. For example, Straube and colleagues (2011) found that although the posterior middle temporal gyrus was activated for both iconic gestures' and metaphorical gestures' integration with speech, the left inferior frontal gyrus was only activated for metaphorical gesture and speech integration. The authors argue that this reflects the difference between the two types of speech-gesture integration in perceptual matching and higher order relational processing (Straube, Green, Bromberger & Kircher, 2011).

Brain Lesion Studies

One approach to understanding how language and gesture are connected is to look to patients with impaired language and see what their gestures are like. Using this approach many patients with aphasia have been studied. The current review will mainly compare Broca's and Wernicke's aphasia patients. These two types of aphasia differ in two main ways. Broca's aphasia is often related to poor expressive language skills, in particular difficulties with grammar (Kean, 1977). Patients with Broca's aphasia often have relatively good speech comprehension, although this again is limited by their agrammatism (Kean, 1977). In contrast, patients with Wernicke's aphasia are typically fluent in their speech, such that they have relatively intact syntactic skills, but their speech is often meaningless (e.g. Kean, 1977). Further, patients with Wernicke's aphasia also have poor comprehension skills (Geschwind, 1970).

As mentioned earlier, Broca's aphasia is characterised by severe grammatical impairments, while patients with Wernicke's aphasia demonstrate semantic impairments. These impairments can also be observed in their gesture production (e.g. Cicone, Wapner, Foldi, Zurif & Gardner, 1979). For example, patients with Broca's aphasia produce a high number of clear gestures with referential content whereas patients with Wernicke's aphasia produce quite complex gestures but are lacking in referential content (Cicone et al., 1979). This is consistent with more recent work which found that patients with Broca's aphasia used a high proportion of meaningful gestures such as iconic gestures or pantomimes, while Wernicke's aphasia patients used more abstract gestures such as beat gestures (Sekine, Rose, Foster, Attard & Lanyon, 2013). Cicone and colleagues (1979) suggest that this mirroring of impairment in speech and gesture reflects a '*central organiser*', which controls communication regardless of modality. This is in line with other theories suggesting that gesture and language share a computational stage (McNeill, 1985). Finally, Sekine and colleagues (2013) propose the dual-factor hypothesis. This hypothesis suggests that gesture use is determined by 1) whether the speaker feels a gesture is useful and 2) whether the speaker has the capacity to represent meaning in gesture. Whereas both aphasia groups may feel gestures would be useful, they differ in their abilities to produce meaningful gestures appropriately (Sekine et al., 2013).

Other research has looked more closely about the types of iconic gestures and the types of language impairments patients have. For example, Hadar and colleagues (1998) compared the gestures of three groups of aphasic patients with different primary impairments: semantic (e.g. impaired naming skills), phonological (e.g. impaired repetition skills) or conceptual impairment (e.g. impaired sentence comprehension, and impaired picture arrangement abilities). The results showed that patients with a conceptual impairment produced a higher rate of indefinite gestures and a lower rate of iconic gestures compared to healthy controls. Patients in this group also synchronised their gestures less well to their speech. In contrast, patients with either primary semantic or phonological impairments showed similar rates and types of gestures as healthy controls (Hadar, Wenkert-Olenik, Krauss & Soroker, 1998). This pattern of results may reflect the association between gestures and conceptualising and packaging our thoughts into units that can be verbalised (See Kita, 2000).

Investigations at the individual level, rather than the group level, have also suggested that gesture and speech share some features of impairment in aphasia. For example, in one case study, an aphasic patient is described as having very good semantic knowledge but has severe anomia, such that he has great difficulty in word finding, and naming (Kemmerer, Chandrasekaran & Tranel, 2007). In contrast to his severe word finding difficulties, the patient could produce iconic gestures to describe scenes that were sensitive to the semantics of the verbs and prepositions, and may even have been sensitive to the syntactic structure of the sentences he could not form (Kemmerer et al., 2007). This case-study demonstrates a close association between gesture and speech impairments, such that they are often impaired in similar ways, as the result of brain lesions.

There is also evidence that patients can use gesture to compensate for language impairment. For example, if gesture rate is measured in terms of gestures per spoken word, patients with Broca's aphasia gesture at a higher rate than healthy individuals (Feyereisen, 1983). Similarly, it has been shown that aphasia patients tend to gesture more in pauses in speech, compared to healthy controls (Hadar et al., 1998). In particular, research has shown that patients with Broca's aphasia, typically associated with disfluent speech, gesture almost twice as much as patients with Wernicke's aphasia (as measured by rate per 100 words) (Sekine et al.,2013).

Therapies directed at patients with aphasia acknowledge that gestures may play a role in recovery. Although further research is needed in this area, there is now support that multimodal interventions, which encourage and develop communication regardless of modality, can be beneficial in rehabilitation (Rose, 2013). This suggests that using gesture can be one way to boost language recovery in patients. In Chapter 8, the current thesis investigates whether gesture (specifically right-handed gestures) can improve performance on a word learning task in typically developing children.

It should be noted that the research on gesture therapies for patients with aphasia is not consistent, with some research finding that speech based interventions are more effective than gesture based ones (e.g. Marshall, Best, Cocks, Cruice, Pring, Bulcock et al., 2012) and others showing large variability between patients (e.g. Rose & Sussmilch, 2008).

It is also possible to study the language skills of people suffering from apraxia. Papeo and Rumiati (2013) found that verbal labelling of pictures and emblems was associated with patients' difficulties in both producing emblems after imitation and after verbal cues. Similarly, in another study, Papeo and colleagues (2010) found an association between patients' abilities to verbally label the action an actor was pantomiming (with verbs) and their abilities to imitate the same pantomime. These studies seem to show the close association is between verbal and non-verbal communication in terms of how they breakdown. However, both studies also find evidence of double dissociations between patients' verbal and non-verbal abilities (Papeo & Rumiati, 2013; Papeo, Negri, Zadini & Rumiati, 2010), although the numbers of participants in these studies were small. For example, in the pantomime study three patients performed poorly on the imitation task, but relatively well (two were in the normal range) for a verb comprehension task. To complete the double dissociation, two patients showed the reverse effect: namely, they performed poorly in the verb comprehension task but relatively well (one was in the normal range) for the imitation task (Papeo et al., 2010). Thus, it appears that at least on some level, verbal and non-verbal abilities do not rely on the same neural networks: it is possible for individuals to produce the motor action to imitate a pantomime gesture without understanding the verbal label for that action (Papeo et al., 2010).

5.5

HANDEDNESS AND LANGUAGE

Manual handedness and language

For a long time, people have found an association between manual handedness and language lateralisation (e.g. Rasmussen, & Milner, 1977). Now, with improved technology, the evidence for this is more convincing than ever. For example, Knecht and colleagues (2000) used functional transcranial Doppler sonography and found a clear relationship between the cerebral dominance for language and handedness, such that only 4% of right-handed individuals had right lateralised language, while 27% of left-handed individuals showed this pattern.

Research has also shown an association between manual handedness and language development. For example, Ramsay (1984) found that infants began to demonstrate a right-hand bias when manipulating objects, in the same week that they began to babble. Previous to this week, infants had not shown a manual hand preference (Ramsay, 1984). Further, there is some evidence for a relationship between left-handedness and language impairment. For example, Bishop (2005) found children with specific language impairment (SLI) used their left hand to file cards on the left of the midline more than typically developing children. Similarly, research has shown a possible relationship between left-handedness and developmental dyslexia, although the nature of this association remains unclear (see Beaton, 1997, for a review of the evidence and Eglinton & Annett, 1994, for a meta-analysis).

Gesture Handedness and Language

Given that there is strong evidence for an association between language and gesture, and we have seen that both demonstrate a left cerebral dominance, we now consider how language and gesture handedness interact. Kimura (1973a, 1973b) found that gesture production is significantly influenced by which hemisphere is dominant for language processing. For example, in a sample of right-handed adults, four out of six participants who gestured more with the left hand than the right hand showed a left-ear advantage (which suggests right-hemispheric dominance for language processing). Conversely, 25 out of 28 participants who gestured more with their right hand than the left hand showed the usual right-ear advantage (Kimura, 1973a). Further, it has been shown that left-handed adults with a right-ear advantage may use a more similar gesture pattern to right-handed adults with a right-ear advantage, compared to left-handed adults with a left ear advantage (Kimura, 1973b). However, manual handedness also influences gesture handedness, as left-handed adults, regardless of their ear advantage, made more left-handed gestures than right-handed ones (although for the individuals who showed a right-ear advantage, this difference was very small) (Kimura, 1973b). To briefly summarise, cerebral dominance for language has a large influence on gestural handedness, such that adults with left lateralised language show more right-handed gestures than would be predicted based on their manual handedness alone.

More recently, research has shown that laterality indexes for silent language production and gesture planning, both measured using fMRI techniques are positively correlated in healthy left-handed adults (Kroliczak, Piper & Frey, 2011). This correlation has also been replicated by Vingerhoets and colleagues (2013) in a study of participants with typical and atypical language lateralisation and regardless of their manual handedness. This pattern was observed at the group level and also at the individual level, such that if a person showed right-hemispheric dominance for language, they also showed a right dominance for pantomiming tool use (Vingerhoets, Alderweieldt, Vandemaele, Cai, Van der Haegen, Brysbaert et al., 2013). In other words these studies found that when adults had atypical dominance for language, they also showed a similar atypical pattern for gesture processing.

Research has shown that the type of linguistic processes can influence gesture handedness. For example, when people are speaking metaphorically this right-hand bias is reduced (Kita, de Conappa & Mohr, 2007). More specifically, Kita and colleagues (2007) found that, when looking at character viewpoint depictive gestures (such as, pretending to throw a ball, as compared to tracing the trajectory of an object's movement, known as observer viewpoint gestures), the left hand is used relatively more often when people are interpreting metaphorical phrases (e.g. '*he spilled the beans*' to mean let out a secret) than when they are explaining concrete phrases (e.g. '*he spilled the marbles*') or abstract phrases (e.g. '*to disclose something confidential*'). The authors argue that this is due to the increased involvement of the right hemisphere in this type of linguistic processing (Kita et al., 2007).

Further, Argyriou and Kita (2013) manipulated gesture handedness to investigate the relationship between metaphorical speech and left-handed gestures. Specifically, when participants were instructed to use their left hand, they produced more metaphorical explanations of phrases, compared to when they used their right hand, or were prohibited from gesturing at all. These studies show that in adults, there is an association between gesture handedness and language.

There is also a wide range of developmental evidence linking right-handed gesturing and key milestones in language production. For example, Locke and colleagues (1995) found an increase in right-handed shaking behaviours around the time that infants began to babble. Similarly, Cochet and colleagues (2011) found that toddlers were more right-handed for pointing gestures after the vocabulary spurt (50 words) than before. Similar patterns have been also been seen in receptive language development. For example, Esseily and colleagues (2011) found that vocabulary development (receptive and expressive) at in 14- to16-month-olds correlated with a right bias for pointing.

Research has also investigated the impact on gesture handedness when language breaks down, as in the case of aphasic patients. Foundas and colleagues (1995) found that although healthy adults gestured more with their right hands, aphasic patients were just as likely to produce gestures with either hand. Although the patients studied had ideomotor apraxia (difficulty in executing planned movements based on semantic memory), they did not show impaired fine or gross motor skills. Further they did not show any signs of hemiparesis, so that the change in their gesture handedness was not due to not being able to use the right hand as much as healthy participants (Foundas, Macauley, Raymer, Maher, Heilma & Rothi, 1995). This study shows that the impact of impaired language can be observed in gesture handedness. Thus, the impairment of language in the left hemisphere is associated with the impairment of gesture in the same hemisphere.

5.6.

OVERALL CONCLUSIONS

The relationship between language and gesture in the left hemisphere is critical to the second half of the current thesis. This review has shown that early on in development that language and gesture become lateralised to the left hemisphere. Further, it also reviewed evidence that language and gesture are associated at a neuro-physiological level. It is clear from this review that handedness, and in particular gesture handedness, and language are associated in the left hemisphere, but it remains unclear how this association develops and whether it can be used to encourage more efficient vocabulary development.

The rest of the thesis focuses on how vocabulary development and right-handed gesturing develop in infancy and early childhood. Chapter 6 first investigates the relationship between these two factors in young infants (10-12 months). This age is particularly important because it corresponds to the first acts of referential communication, i.e. first words and first gestures. Understanding how gesture and vocabulary are associated in the left hemisphere at this early age is, therefore, fundamental to understanding the basis of their relationship. Are referential speech and gesture associated already at this age, or does this relationship require additional experience and therefore only emerge later in infancy or childhood? Other work on early speech and gesture handedness has focused on older infants who already have experience of both modalities.

Chapters 7 and 8 then investigate the relationship between gesture handedness and vocabulary development in 3-year-olds. This is an age range that has not been previously studied in this context, yet is an age when language development is very dramatic.

Chapter 7 investigates the relationship between right-handed pointing and verb learning by reanalysing data from the study described in Chapter 4. Specifically this chapter investigates whether there is an association between speech and gesture integration during a word learning task and the likelihood of using the right hand to respond in the same task. This is important as it can shed light on the relationship between word storage and retrieval and gesture production in the left hemisphere. If there is an association, it provides evidence for neural overlap.

Chapter 8 is the final empirical chapter and the first to manipulate gesture handedness with young participants in the context of a word learning task. This chapter builds on previous studies, which have used correlational and observational data, to investigate the nature of the relationship between right-handed gesturing and language acquisition.

Finally, vocabulary development at both of these age groups is very important and so gaining a full understanding of the mechanisms that can support this is crucial. The second half of this thesis investigates how language and gesture at these ages are associated in the left hemisphere can inform our theories of lateralisation and have important practical implications.

CHAPTER 6

LINKS BETWEEN GESTURE HANDEDNESS AND LANGUAGE DEVELOPMENT AT THE ONSET OF REFERENTIAL COMMUNICATION

6.1. Goals and Motivation

This paper investigated the co-development of language and right-handed pointing in 10 to 12-month-old infants. Studying gesture handedness can give an indirect measure of which hemisphere is dominant for gesture production, such that right-handed gesturing is associated with left-hemispheric dominance. There are now many converging lines of research that language and gesture are part of one system (McNeill, 1985) and that this is typically lateralised to the left hemisphere (e.g. Kimura, 1973a, 1973b). What remains unclear is how this system develops; are language and gesture always associated, or have they become associated through experience? Previous studies have failed to control for the effects of general maturation, or the possibility that vocalisations could lead to the observed association (by increasing the activity in the left hemisphere, the right hand may be more likely to be used in gesturing). Further, research has been completed on very young infants and toddlers but the months just before the first birthday have not been explored as thoroughly in this area. This age is critical in both gesture and language development as it is the age at which both first words and first points emerge.

The current study aimed to further previous research by in two main ways. Firstly, by measuring several variables, the current study aimed to rule out the possibility that language and gesture are linked indirectly, through a third variable. Specifically, the current study aimed to rule out the possibility that language and gesture were linked by general maturation, or by increased activation in the left hemisphere through the production of vocalisations. Secondly, the current study investigated the association between language and gesture at the onset of referential communication, where the possibility of an association being due to experience is limited.

6.2. ARTICLE 3

AT 10-12 MONTHS, LANGUAE AND GESTURE DEVELOP HAND-IN-HAND IN THE LEFT HEMISPHERE

Abstract

The close association between language and gesture has been widely studied (McNeill, 1985). It remains unclear, however, when and how this relationship originates ontogenetically. The current study investigated the relationship between vocabulary development and pointing handedness in 10 to 12-month-old infants. The study used cross sectional data from 16 infants. Infants took part in an imperative pointing elicitation task and a grasping task in order to assess their pointing and grasping handedness. Further, parents filled out the Oxford Communicative Development Inventory (CDI) (Hamilton, Plunkett, & Schafer, 2000) in order to assess infants' receptive and productive vocabularies. The result showed a positive, significant correlation between receptive vocabulary development and right-handed pointing. This relationship was not due to age or to vocalisations, which have not been ruled out by previous studies. Thus, at the onset of referential communication gesture and language develop together in the left hemisphere. Possible mechanisms behind this co-development are discussed. Additionally, the study found a positive correlation between the number of points infants produced and their productive vocabulary, which can be attributed to an underlying ability to referentially communicate at this young age.

Key Words : Vocabulary development, gesture development, lateralisation

Referring to objects and events is a key corner stone of human communication. This ability emerges towards the end of the first year of infants' life. Infants start to produce their first word around 10 to 14 months (Iverson & Goldin-Meadow, 2005) and their first pointing gestures at around 11 months (Butterworth & Morissette, 1996; Bates, 1976). The current study investigated the relationship between pointing gestures and vocabulary development in 10 to 12-month-old infants.

The idea that gesture and language are processed by one unified communicative system (McNeill, 1985) has drawn much attention in the recent literature. For example, some argue that the close relationship between speech and gesture is one piece of evidence for gestural origin of language in evolution (e.g., Corballis, 2003) and for embodied nature of language processing (e.g. Glenberg & Gallese, 2012). This relationship has also been intensively investigated to develop theories of language development (e.g. Iverson & Goldin-Meadow, 2005). A growing body of neuroscientific evidence supports the idea of speech and gesture as a unified system (e.g. Gentilucci & Volta, 2008; Bernardis & Gentilucci, 2006). Kimura (1973a, 1973b) found that the hemisphere that was dominant for language, as assessed by a dichotic listening task, also influenced gesture production; that is, the hand contra-lateral to the language dominant hemisphere was used more often for gesture production than would be predicted by manual handedness patterns alone. Although language and gesture in adults may share a common neural basis, it remains unclear how this relationship originates ontogenetically.

A right-hand bias for gesture production in infants and children (e.g. Locke, Bekken, McMinn-Larson & Wein, 1995; Cochet, Jover & Vauclair, 2011; Esseily, Jacquet & Fagard, 2011; Vauclair & Imbault, 2009) as well as non-human primates (Meguerditchian & Vauclair, 2009) suggests that the left hemisphere is dominant for gesture production. Further, it is well-known that the left hemisphere is typically dominant in language processing (e.g., adults: Knecht, Drager, Deppe, Bobe, Lohmann, Floel et al., 2000; Kimura, 1973a, 1973b; infants: Holowka & Petitto, 2002; Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002). For children, right-handed gesture lateralisation patterns appear to be particularly clear during key points in language development. For example, Locke and colleagues (1995) found a relationship between the onset of babbling and right-handed, repetitive shaking actions in 18-28 week old infants. Similarly, Cochet and colleagues (2011) found that children became more right-handed for pointing around the time of their lexical spurt (14-20 months). Furthermore, 14-to-16-month-olds with a right-hand bias for pointing had larger vocabularies than infants without such a bias (Esseily, et al., 2011). However, this study did not consider age and vocalisation in the analysis; therefore, the relationship between right-handed pointing and vocabularies may have simply been due to general maturational factors (independently related to pointing and language) or due to temporary activation of the left hemisphere during vocalisations, which may be more frequent in infants with larger vocabularies.

Current study

The current study investigated whether, in 10 to 12-month-old infants, vocabulary development and a right-hand bias in imperative pointing are associated in the way suggestive of co-development of language and gesture in the left hemisphere. More specifically, we examined how frequency and right-hand bias in imperative pointing gestures are related to vocabulary size. The design of the study allowed us to rule out temporally activation of the left hemisphere due to vocalisation or general age-related maturation as the explanation for these associations.

We investigated 10 to 12-month-old infants, who are at the very onset of referential communication, because their experience of producing pointing gestures is very limited, and specifically, there is very limited experience of meaningfully combining speech and gesture (Bates, 1976; Iverson & Goldin-Meadow, 2005).

We examined imperative pointing (used to request an object), as opposed to declarative pointing (to share attention about an object with another person) (Bates, Camaioni & Volterra, 1975). Previous research has suggested that declarative points are more associated with vocalisations (Cochet & Vauclair 2010) and language development (Colonnesi, Stams, Koster & Noom, 2010) than imperative points. Rather than being associated with language, imperative points have been suggested to have originated from reaching actions (See Cochet & Vauclair, 2010). However, research with chimpanzees has found an association between imperative points and vocalisations (Hopkins & Cantero, 2003), suggesting this type of gesture may be more associated with vocal or speech communication than previously thought. Further, imperative pointing allowed us to design the pointing task to be as similar to the grasping task as possible.

The study also elicited manual handling of toys in order to obtain grasping handedness scores. Further, parents completed the Oxford Communicative Development Inventory (CDI) (Hamilton, Plunkett, & Schafer, 2000) to assess vocabulary development. We predicted that a larger vocabulary would be associated with more right-handed pointing, but not with the proportion of right-handed object manipulation.

Method

Participants

Twenty-eight 10 to 12-month-old infants took part in the study (15 females and 13males, *M*= 335.5 days, *SD* = 27.9). Twelve infants were excluded from the study; six produced no points, five only produced one point each and one infant's score for receptive vocabulary was over 2.5 *SD* above the whole group's mean (*M*= 11.1, *SD*=9.41, *individual's score* = 38.0). Therefore, the final data sample came from 16 infants (10 females and 6 males; *M*= 337.6 days, *SD* = 26.8).

Of these 16 infants, 12 were described by their parents as being White-British, one was described as White-Other and three were mixed ethnicity. Fourteen were English monolingual and two were also acquiring German. Eight children did not have siblings, seven had one older sibling and one was the youngest of four siblings. Four children had had at least one ear infection. Nine children had at least one parent who is educated to at least Bachelor's degree level, five had at least one parent who is educated to some college/ university level, and two had at least one parent who is educated to high school level. The fathers of all children were in full time employment. Five of the mothers were currently on leave from work, or stay at home parents, eight were employed part time and three were self-employed.

Participants were recruited through a university database. Families were reimbursed £10 in travel expenses and received a toy in return for participation. Although when parents were first contacted about the study, they were informed that it was investigating pointing gestures, they were not asked explicitly whether or not their infant used points to communicate.

Stimuli

The study used the Oxford CDI (Hamilton et al., 2000) to obtain an index of infants' productive and receptive vocabulary development. This is a check list of 416 words, which parents tick if they believe their child understands, or understands and says. Scores for productive and receptive vocabulary can then be worked out as a percentage of the total number of items on the list.

This study used 20 small, attractive toys (e.g. coloured cars) to elicit gestures and grasping actions (one toy per trial). The toys were roughly symmetrical, so as not to bias hand choice. The order of toys and whether the toys were used in grasping or pointing trials was counterbalanced.

Procedure

Testing occurred in a small room, in a baby lab at the University of Birmingham. Although the infants had chance to interact with the experimenter before the experiment took place, there was no official or structured warm-up period.

All participants took part in both the grasping and the imperative pointing task. The order of tasks was counterbalanced across participants. There were 10 trials per task (20 trials in total). Infants carried out the two tasks one after the other without any break in between. For both tasks, the infants sat on their mother's lap. Mothers were instructed not to talk to their infant or to try to guide their attention. See Figure 6.1 for the setup in both tasks. The experimenter always handled the toys bimanually, so as not to bias hand choice in the current and subsequent trials.

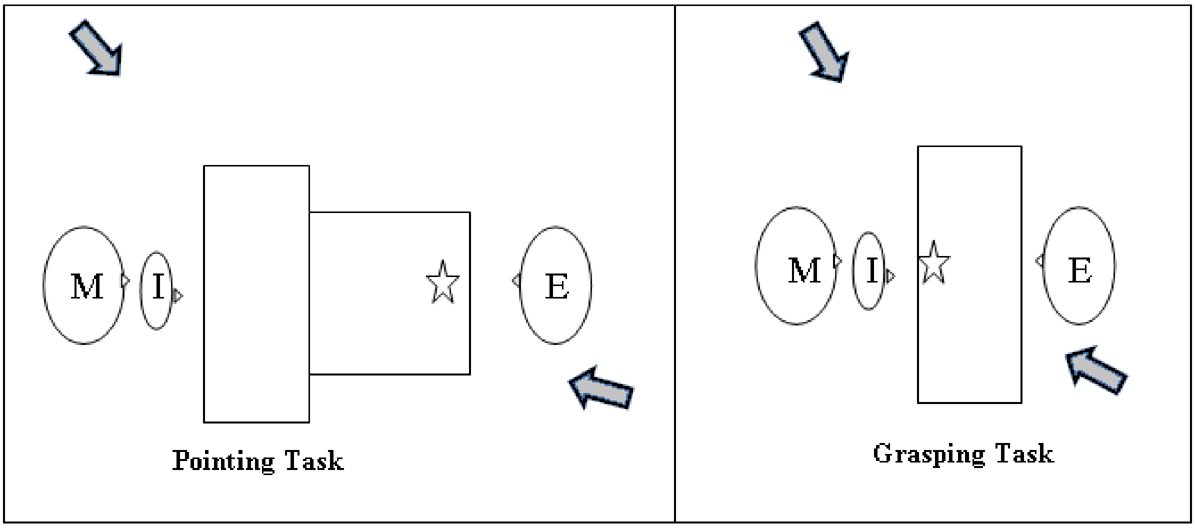


Figure 6.1. The setup for both tasks (not drawn to scale). 'M' indicates the mother, 'I' indicates the infant and 'E' indicates the experimenter. The rectangles depict tables and the star depicts the location of the toy. The arrows represent the location and direction of the cameras.

For both tasks, at the start of trials the experimenter held up a toy, shook it and said '*Look at this!*' For the pointing task, the toy was then put on the table in front of the experimenter (approximately 120cm from the infant). For grasping trials the toy was placed in easy reach of the infant (approximately 10cm from the infant). The experimenter then waited for 15 seconds. In pointing trials, if the infant pointed (or tried to reach for the toy), the toy was given to them. If they did not point or reach during these 15 seconds, the experimenter repeated the process (saying: '*Look at this! Isn't it pretty!?*'). If they did not point or reach after the second set of 15 seconds the toy was given to them. Grasping trials followed the same procedure, except that the target action was grasping of the toy rather than pointing (or reaching) towards the toy.

In addition to these tasks, mothers were asked to complete the Oxford CDI.

Coding

Two video recorders were used, one facing and one from the side of the infant. These videos were synchronised and coded using the video annotation software ELAN (European Distributed Corpora Project [EUDICO] Linguistic Annotator, developed by the Max Planck Institute for Psycholinguistics.

All gesture information came from pointing trials and all grasping information came from grasping trials. In pointing trials, gestures were coded from the moment that the toy became visible to the infant, until the end of either a failed reach or a point, or the end of the trial if children did not reach or point. In grasping trials only grasping was coded.

Gestures were coded into one of five gesture types (points, failed reach, banging the table, waving, other) but as this paper focuses on points only these will be discussed. Points were defined as the infant extending one or both of their arms towards the toy or upwards, without leaning forward. This is in contrast to failed reaches, where the infant extended their arm/s and also leaned towards the toy. Thus, whether or not an infant leaned, was the distinguishing feature between pointing and failed reaching. Gestures directed at other objects were not coded. Grasping of a toy was coded for infants' initial touch (e.g. lifting, rolling or stroking the toy).

Each action was coded for hand choice: left, right and bimanual. Grasps were coded as bimanual if both hands made contact with the toy within five frames of each other. Gestures were coded as bimanual whenever both hands were used, regardless of the size or duration. Bimanual actions were further coded by dominance as left, right or equal. For gestures, dominance was determined by the leading hand or the hand that made the bigger gesture. In cases where one hand started the gesture but the other was larger, or if dominance appeared to change hands over the gesture, then they were coded as equal. For grasps the dominant hand was the one that appeared to be most in control of the toy.

We obtained high inter-coder reliability for the coding. See Appendix 8 for more details.

Speech-like vocalisations were coded during pointing trials, from when the toy became visible to the infant to when the infant made a failed reach or pointing gesture (or until the end of the trial if the infant did not point or reach). They were coded using a binary system (vocalisation or no vocalisation) and included babbling, whining, and humming but not coughing, crying or laughing.

Hand shapes of points were also coded for, since research has shown that different pointing functions are associated with different forms. Specifically, infants are more likely to use an open hand/ spread shape for imperative points and an index finger shape for declarative points (Cochet & Vauclair 2010). Points were coded as one of six hand shapes: *index finger* (prototypical pointing shape), *index separate* (index extended and other fingers curled but not tightly), *spread* (all fingers extended), *relaxed* (hand appears relaxed with no clear fingers extended or tightly curled), *fist* (all fingers curled into a fist) and *other* (arrangement of fingers did not fit any of the other categories).

Analysis

The receptive and productive vocabulary variables were measured using the Oxford CDI (a parental questionnaire). The scores represent the percentage of words on the list that parents reported that their infant understood or spoken. A large CDI score, therefore, reflects more words understood or produced. The study also measured the number of points produced in the pointing trials (range: 2-10), age (in days) and the proportion on time spent vocalising within pointing trials.

Finally the study measured handedness for grasping and pointing for each infant. Handedness scores were calculated using the following formula:

$$\text{Handedness} = (R - L) / (R + L + B_{equal})$$

R = the number of uni-manual right-handed action + the number of right dominant bimanual action

L = the number of uni-manual left-handed action + the number of left dominant bimanual action

B_{equal} = the number of bimanual action with no clear dominant hand

Thus, a score of 1 reflects a pure right-hand bias and a score of -1 reflects a pure left-hand bias. A score of 0 reflects an absence of a bias.

Results

Exclusions

Of the 16 infants included in the main analysis, six handling trials were excluded. Four of these were due to an experimenter error: for one trial, a toy was placed on the infant's hand, for another trial, a toy was placed at the wrong orientation, and for two trials, toys were given without the verbal phrase '*Look at this*'. Two other trials were excluded due to infant behaviours: one toy was not picked up at all, and in one trial a child was not sat centrally.

Therefore the final count for handling trials was 154 (16 participants x 10 trials – 6 exclusions).

Data from two pointing trials (both from the same participant) were excluded due to infant fussiness.

Descriptive statistics

The final analysis included 89 points, made up from 48 uni-manual points and 41 bimanual points (of which 31 were coded as having a dominant hand), and 154 grasping actions, made up from 97 uni-manual grasps and 57 bimanual grasps (of which 21 were coded as having a dominant hand). The scores were as follows: pointing handedness, M= .190, SD= .572; grasping handedness, M= .157, SD= .425; receptive vocabulary, M= 10.1, SD = 8.34; productive vocabulary M= .736, SD= .782. Further, on average infants produced 5.56 (SD= 2.58) points over the ten pointing trials (range: 2-10). The mean proportion of the time in pointing trials spent vocalising was .0607 (SD= .0454).

A t-test found that there was no significant difference between grasping and pointing handedness scores. Further, as a group, neither infants' grasping handedness nor their pointing handedness was significantly different from 0, showing that they did not have any global handedness bias.

Of the 130 hand shapes that made up the 89 points (48 unimanual + 2* 41 bimanual), 39 were coded as index separate, 28 were coded as spread, 26 were coded as index finger, 22 were coded as relaxed, 8 were coded as fist and 7 were coded as other. Due to the small number of data points in each category this data was not analysed further.

Correlational analysis

Relationship between language and pointing handedness

First, the relationship between productive/ receptive vocabulary and pointing handedness was investigated. The results of Spearman's correlations showed that there was a moderate, positive correlation between pointing handedness and receptive vocabulary scores (Spearman's R = .506, N= 16, p=.046), see Figure 6.2. That is, infants who had a large receptive vocabulary also showed a larger right-hand bias for pointing. There was no relationship between expressive vocabulary and pointing handedness (p>.1).

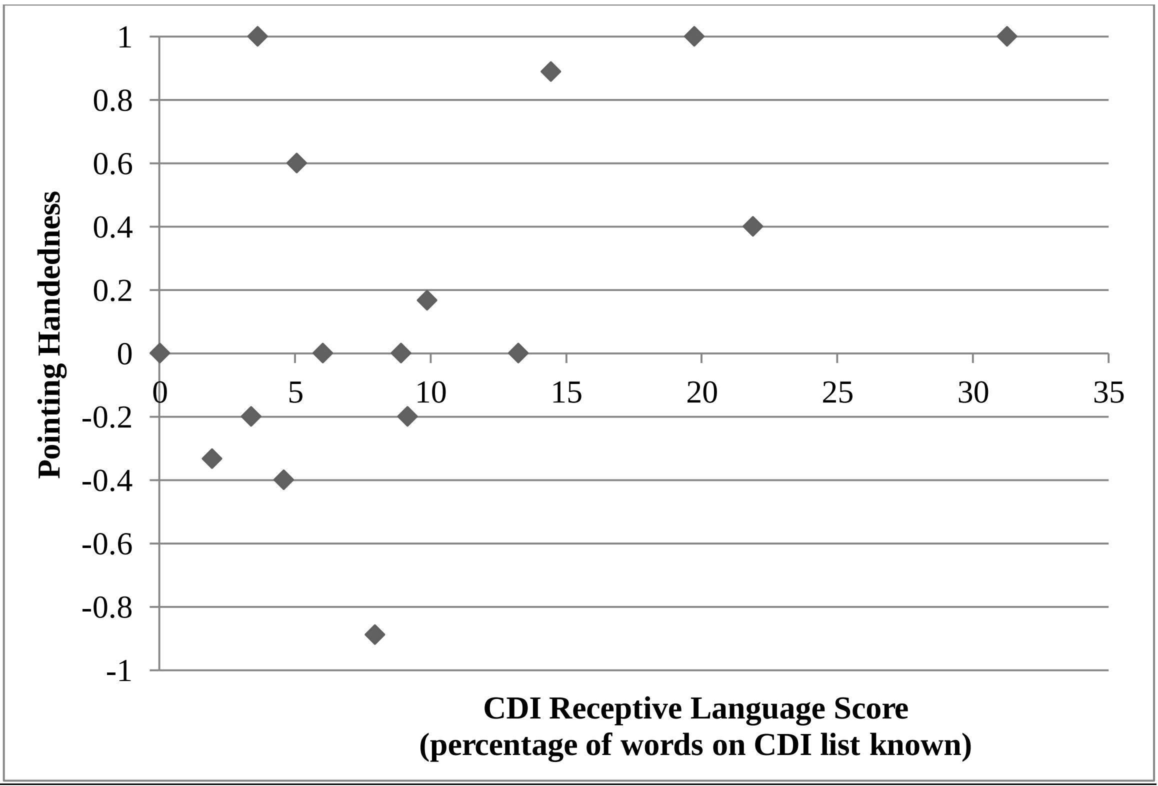


Figure 6.2. Scatter plot of infants' receptive vocabulary size (CDI receptive scores) and pointing handedness (-1 reflects a pure left-hand bias, 1 reflects a pure right-hand bias, 0 reflects an absence of a bias)

Importantly, neither receptive vocabulary scores nor pointing handedness correlated with age or the proportion of time spent vocalising (p>.1 for both). Further, partial correlations, between receptive vocabulary and pointing handedness remained significant after controlling for either age (R (13) = .533, p=.041) or the proportion of time spent vocalising (R (13) = .530, p =.042).

Relationship between language and grasping handedness

Next, the relationship between productive/ receptive vocabulary and grasping handedness was investigated. The results of Spearman's correlations revealed that neither vocabulary measure correlated with grasping handedness (p>.1 for both).

Relationship between pointing and grasping handedness

Next, the relationship between the two handedness measures was investigated. The results of a Spearman's correlation revealed no association between the two (p>.1).

Relationship between language and number of points

Finally, the relationship between receptive/ expressive vocabulary and the number of points produced in the study was investigated. The results of Spearman's correlations showed a strong, positive correlation between the number of points and productive vocabulary scores (Spearman's R= .794, N= 16, p<.001), see Figure 6.3. That is, infants who had a large productive vocabulary also produced a larger number of points during the study. There was no correlation between receptive vocabulary and the number of points produced (p>.1).

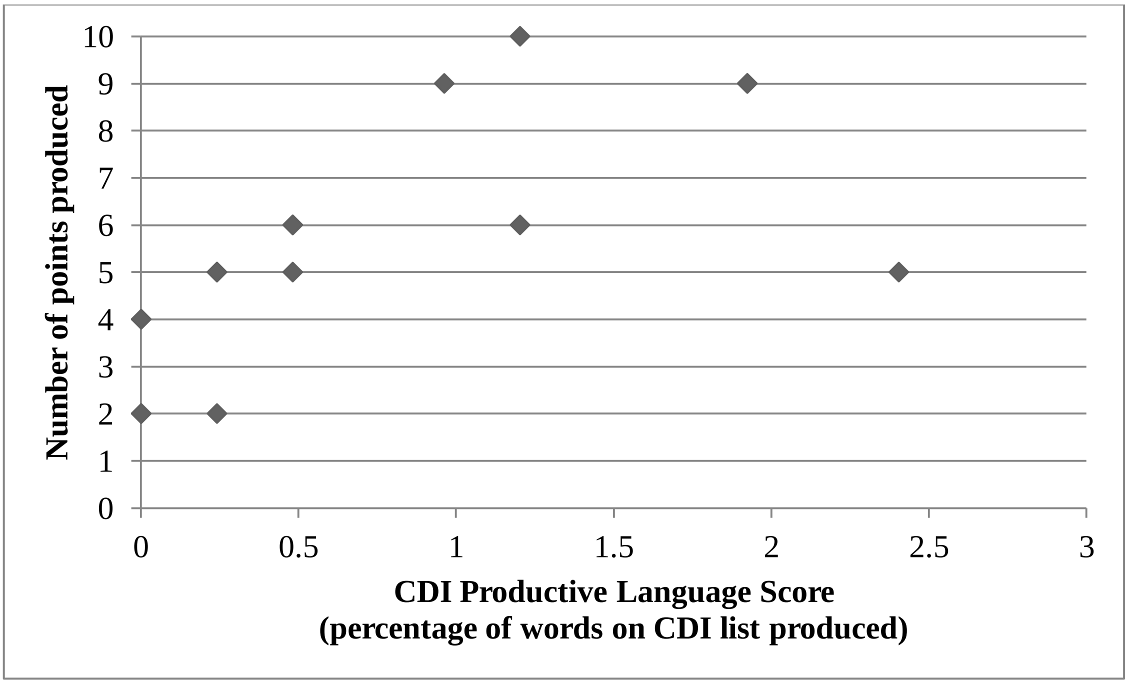


Figure 6.3. Scatter plot of infants' productive vocabulary size (CDI productive scores) and the number of points produced during the pointing trials in the study.

Importantly, although there was a marginally significant correlation between age and the number of points produced (R (16) = .472, p=.065), age did not correlate with productive vocabulary size (p>.1). Further, a partial correlation between productive vocabulary size and number of points remained significant after controlling for age (R (13) = .541, p=.038) suggesting that the relationship was not due to general maturation.

Discussion

The present study investigated the relationship between hand dominance and frequency in pointing gesture and vocabulary development in 10-12-month-olds, who are at the very onset of referential communication (pointing and first words). We found that infants' receptive vocabulary was positively correlated with their pointing handedness, such that the larger the receptive vocabulary was, the more right-handed their pointing was. Furthermore, handedness for objective manipulation was not correlated with receptive vocabulary. This suggests that towards the end of the first year of life the processing centre for referential communication in the left hemisphere starts to control both linguistic and non-linguistic information. Importantly, this relationship was not mediated by age or the amount of time spent vocalising, ruling out general maturation and the temporary activation in the left hemisphere as explanations.

It is important to note that the use of pointing gestures by an infant may influence a parent's perceptions of their infant's receptive vocabulary (e.g. they can respond to questions using points). This could alter how parents complete the Oxford CDI and inflate vocabulary scores in a way which may not accurately represent their infant's lexical knowledge. However, this is unlikely to have driven the observed pattern, since the dependant variable was gesture handedness, rather than use of gestures. It is unlikely that parents will perceive their infant as understanding more words if they use their right hand to point as compared to their left.

The study also found s positive correlation between infants' productive vocabulary and the number of points they produced, such that the larger the productive vocabulary was, the more pointing gestures they produced. This is consistent with recent research showing a similar association between pointing frequency and vocabulary (both receptive and expressive) for declarative points (Jacquet, Esseily, Rider & Fagard, 2012). This is consistent with a recent meta-analysis showing a relationship between pointing and declarative pointing (Colonnesi et al., 2010). In the current study, this relationship may reflect infants' overall tendency to produce referential acts. What mental process that is common to word production and pointing was responsible for the correlation? This common mental process is unlikely to be lateralised to one of the hemispheres because neither the number of points produced nor the productive vocabulary was associated with the handedness for pointing. Thus, the common mental process may not be a part of language or gesture processing per se, which becomes increasingly left-lateralised. We speculate that it may be related to other psychological processes that may determine the frequency of referential acts such as social cognitive abilities necessary for triadic (referential) communication (Tomasello, 2008) or personality (e.g., shyness). Finally, the relationship between the number of points produced and the productive vocabulary was not mediated by age, and so was not a result of general maturation.

Neither the number of points produced nor the productive vocabulary was associated with the proportion of time spent vocalising. This is probably because vocalisations in the study were any speech-like sounds, and therefore included many vocalisations that were not words and thus probably not referential acts (referring to the toy shown to them).

How are gesture handedness and vocabulary associated at this early age?

The current study furthers the literature by addressing the issue of handedness of pointing and language at an earlier age than previous studies (e.g. Cochet et al., 2011; Esseily et al., 2011). It is important to understand how gesture handedness and language can be associated at such a young age. In particular, infants at this age at very limited experience of producing gesture and speech simultaneously in a meaningful sense (Iverson & Goldin-Meadow, 2005.). Therefore, these types of meaningful speech-gesture utterances may not have been responsible for the relationship between gesture handedness and language observed previously.

It is possible that both the gesture system and the language system originate from one communication system (McNeill, 1985), which is weakly lateralised to the left hemisphere and becomes more strongly lateralised as the system develops. For example, research has shown that from a very young age speech perception is left lateralised (Dehaene-Lambertz et al., 2002). A recent event-related potential study (ERP) found that pointing perception in 8-month-old infants elicits similar activation patterns in posterior temporal regions as pointing comprehension in adults (Gredebäck, Melinder & Daum, 2010). Further, research has shown that infants can follow points made to their right visual field around two months before following those made to their left (Carpenter, Nagell, & Tomasello, 1998). This supports the hypothesis that a bimodal communication system similar to adults, exists in infants' left hemisphere prior to the onset of referential communication. Further, language becomes more left lateralised as vocabulary increases during infancy (Mills, Coffey-Corina & Neville, 1997). However, it is unclear why infants with low comprehension scores did not show any right-hand bias in the current study (See Figure 6.2).

An alternative and possibly more plausible idea is that around the onset of referential communication, the two hemispheres undergo functional reorganisation. The left hemisphere, which is known to control language from early on (Holowka & Petitto, 2002; Dehaene-Lambertz et al., 2002), may also start to control gesture production. Further, this process appears to be directly associated with infants' language development, as infants with less developed language did not show a right bias. Furthermore, this association between language and gesture in the brain is developing before infants begin to produce gesture-speech combinations (Iverson & Goldin-Meadow, 2005). It is possible that the reorganisation may be the result of social environment, rather than biologically hard-wired functions of the two hemispheres, as we detail in the following section. To conclude, in the earliest phase of the development of referential communication in infants, as language comprehension develops, the left hemisphere becomes the processing centre for both language and gesture.

It should be noted, however, the left lateralisation for the multimodal communication system in adulthood cannot be absolute. This is because split brain patients can produce left-handed speech-accompanying gestures (originating in the right hemisphere), despite their language being confined to the left hemisphere (Kita & Lausberg, 2008).

How might receptive language abilities and gesture handedness become associated through social interactions?

We suggest two possibilities, which both arise from caregiver-infant interactions, but differ in the directionality of the effect. At this time these are both speculation and are not mutual exclusive of each other, such that they may both co-exist. It is an important future research topic to tease apart these possibilities.

The first possibility is that language comprehension processes in the left hemisphere pulls the gesture production system into the same hemisphere. Caregivers may ask their infants questions (e.g. "*Where's the doggie?*"), and infants may respond by pointing at the referent (e.g. DeLoache & Demendoza, 1987). Speech perception may activate the left hemisphere (Dehaene-Lambertz et al., 2002), biasing infants to point with their right hand. Having a larger receptive vocabulary will enable infants to experience more of this type of interaction, which makes it more likely that the left hemisphere becomes the default hemisphere to produce points (even when they are not answering a verbal question).

The second possibility is that right-handed pointing facilitates the growth of receptive vocabulary. As most adults have left lateralised language they demonstrate a right-hand bias in gesturing (Kimura, 1973a). It is possible that some infants have a stronger tendency to imitate this right-hand bias than others. When infants point, caregivers are likely to respond verbally, (e.g. "*That's a doggie*" after infant points to a dog) (Kishimoto, Shizawa, Yasuda, Hinobayashi & Minami, 2007). If infants use their right hand to point, this may activate the left hemisphere, which may in turn help the infants to learn a new word in the caregiver's utterance.

Support for this bottom-up priming accounts comes from research showing that when adults tap their fingers they perform better in a word retrieval task than when they do not move their fingers, due to the cortical overlap between motor and speech production areas (Ravizza, 2003). However, further neuro-scientific research is needed to establish how plausible these explanations may be.

Why was only receptive vocabulary, and not productive vocabulary associated, with right-handed pointing?

The current study did not find a relationship between productive vocabulary and gesture handedness, though such an association was found in older infants (e.g. Esseily, et al., 2011). One possible account for this difference is that 10-12-month-olds' productive vocabulary may be limited by other factors that are not related to lateralisation. For example, it may be that at this very young age, productive vocabulary is mediated by the ability to control the vocal apparata. Infants in previous studies, which showed a relationship between productive vocabulary and right-handed pointing, were older and may have not been limited by motor control of vocal apparata.

As infants' motor control increases, their productive vocabulary can develop at a faster rate and can become associated with right-handed pointing, possibly through social interactions as described above. For example, when a caregiver asks '*where's the doggie?*' the infant can point and imitate the word. The speech production will increase activation in the left hemisphere, such that the point is more likely to be right-handed. Further, if a child points to a referent, and a caregiver labels it, the infant can imitate the label. If the infant used the right hand, this may have pre-activated the left hemisphere such that the imitation of the word is more likely to be remembered and may enter into the child's productive vocabulary. Further, as infants age, they are more able to produce meaningful referential speech-gesture combinations. The activation of the left hemisphere caused by the speech, may make the right hand more likely to be selected. Therefore, as infants become more able to articulate words, this can strengthen the association between language development and right-handed pointing in the left hemisphere. Again, these are speculative accounts at the moment and further research should investigate these ideas directly.

Are language development and right-handed pointing associated at the motor planning stage?

In contrast to previous studies, the current study found that receptive vocabulary but not productive vocabulary was associated with right-handed gesturing. Most previous studies which have found a link between language and gesture have focused on language production, such as babbling (Locke et al., 1995) and the lexical spurt (Cochet et al., 2011). This association may be the result of the left hemisphere's advantage in planning motor actions, and not a direct association between gesture and language. The current study, however, found that receptive, rather than productive, vocabulary relates to right-handed pointing development[3]. Further, similar to previous studies (e.g. Esseily et al., 2011; Cochet &

[3] Although Esseily and colleagues (2011) found a relationship between language comprehension and pointing handedness as they failed to account for age and vocalisations, the nature of the relationship is not clear.

Vauclair, 2010), the current study found no association between grasping and pointing handedness, and also no relationship between vocabulary development and grasping handedness. The current study, therefore, shows that the relationship between vocabulary development and right-handed pointing is deeper than an association at the motor planning stage. Communicative hand gestures, but not manual hand actions, do seem to be tied to the language system reinforcing the idea that the two develop together.

The origins and nature of imperative points

Although this study did not specifically investigate the origins of imperative gestures, it is able to shed some light on this debate. Specifically, while handedness for pointing correlated with receptive vocabulary, it did not correlate with handedness for object manipulation. It has been suggested that declarative points are more associated with language development (Colonnesi et al., 2010) and vocalisations (Cochet & Vauclair 2010) than imperative points. Instead imperative points have been suggested to originate from reaching actions (See Cochet & Vauclair, 2010). If this was the case we would have expected a relationship between manual and pointing handedness. Previous studies have found a relationship between imperative pointing handedness and manual handedness in children prior to the lexical spurt (Cochet et al., 2011). However, the current study did not find such an association with 10 to 12-month-olds, who are younger than the youngest infant in Cochet and colleagues (2011). This suggests that imperative points may not have originated from simple failed reaches. This idea is further supported by communicative pointing gestures of non-human primates, which are always imperative. Their pointing gestures demonstrated a stronger right-hand bias than non-communicative hand movements (Meguerditchian & Vauclair, 2009). Taken together, it seems that imperative gestures may be more associated with language, and less with object manipulation, than previously thought. Further research would be needed to specifically target this question.

Imperative pointing at this young age is associated with communication but this type of pointing in older children seems less so. It may be that when children are less mobile and have lower linguistic abilities, imperative points may serve a more important communicative function than later on in childhood. The nature of imperative points may change as infants develop other communicative skills. This is an interesting idea, and suggests that the complexity of very early imperative points may have been overlooked in previous research, and should be considered more carefully.

Implications

The observed relationship may have important practical implications. As infants around this age produce limited spoken language, monitoring their language development is difficult. Although far more research is needed, the current study suggests that gesture handedness could potentially be used as an indicator for language development. However, gesture handedness is unlikely to be useful enough to assess language development on its own, without additional information. However, it may be a useful measure when assessing bilingual children or children whose language has not been well studied and so norms have not been obtained.

General Conclusion

The current study provides evidence that vocabulary and gesture develop together in the left hemisphere at the onset of referential communication. This was not due to general maturation or to temporarily increased activation in the left hemisphere due to vocalisations that accompany pointing. It is possible that both language and gesture are both left lateralised originally. The lack of any right-hand bias in infants with lower language abilities, however, suggests that a reorganisation occurs at the onset of referential communication, such that pointing production becomes more lateralised as language develops. This change possibly develops through infant-caregiver interactions. As the study also found a relationship between productive vocabulary and pointing frequency, it also provides evidence for modality general factors in determining referential acts.

CHAPTER 7

REANALYSIS OF VERB LEARNING DATA IN RELATION TO GESTURE HANDEDNESS

7.1. Goals and motivations

Chapter 4 investigated how gesture could influence children's verb acquisition and then Chapter 6 found that right-handed gestures were associated with vocabulary development in infancy. I was interested to understand whether these two studies might overlap in some way so I decide to look back at my data from Chapter 4. During this study I noted the hand used by children to respond on each trial (not reported in Chapter 4). I was interested, in light of the results from the infant study, to investigate whether handedness differed depending on the responses given.

7.2. ARTICLE 4

GESTURE HANDDNESS AND SPEECH-GESTURE INTEGRATION ARE ASSOCIATED IN A VERB LEARNING

Abstract

The current paper provides a reanalysis of an existing data set on the relationship between gesture and verb learning. Specifically, the current paper investigates how the hand 3-year-olds used to respond in a verb generalisation task, is associated with how well they learned the meaning of a novel verb. The results suggest that that speech-gesture integration was associated with right-handed pointing responses. Specifically, children were more likely to use their right hand to respond when they had incorporated an experimenter's gesture into their representation of a verb's meaning. Additional analysis of uni- vs. bimanual gestures showed that this pattern could not be explained by children paying the right-handed experimenter more attention. Speculative accounts for these patterns are discussed.

Key words: Gesture handedness, word learning

Many researchers are now in agreement that language and gesture are related at least to some degree (e.g. McNeill, 1985). In production, for example, the way information is packaged in speech, influences the way the information is depicted in co-speech gesture (Kita & Özyürek, 2003). In comprehension, gesture and language activate common neurological networks, suggesting that these areas appear to process symbolic comprehension regardless of modality (e.g. Xu, Gannon, Emmorey, Smith & Braun, 2009). Of particular relevance to the current paper, these common areas are typically left lateralised (Xu et al., 2009). Further, language processing in isolation from gestures, is typically left lateralised both in terms of comprehension (e.g. fMRI: Binder, Frost, Hammeke, Cox, Rao & Prieto, 1997) and production (e.g. mouth asymmetry: Graves, Goodglass & Landis, 1982). Similarly, gesture processing in isolation from language, has been shown to be typically left lateralised both in terms of comprehension (e.g. PET: Decety, Grezes, Costes, Perani, Jeannerod, Procyk et al., 1997) and production (e.g. fMRI: Moll, de Oliveira-Souza, Passman, Cunha, Souza-Lima, & Andreiuolo, 2000). Finally, research has shown a relationship between language lateralisation and gesture production handedness (e.g. Kimura, 1973a, 1973b). For example, left-handers with left lateralised language, produce more right-handed gestures than would be expected based on their manual handedness bias (Kimura, 1793b).

Gesturing has been shown to support vocabulary development in both adults (e.g. Kelly, McDevitt & Esch, 2009) and children (e.g. McGregor, Rohlfing, Bean & Marschner, 2009; Goodrich & Kam, 2009). For example, McGregor and colleagues (2009) taught 2-year-olds the word '*under*' whilst using iconic gestures to depict the relational meaning. The results showed that gestures helped children acquire a more abstract and robust representation, compared to seeing other visual aids (McGregor et al., 2009). Further, Chapter 4 of the current thesis found that seeing a speaker's gestures can help children select a specific feature as the referent of a novel verb. These studies show how seeing another person's iconic gestures and vocabulary development can be associated.

The idea that gesture and language share common neurological networks in the left hemisphere (e.g. Xu et al., 2009) can predict and explain the growing number of findings relating language development to right-handed gesturing. For example, Chapter 6 of the current thesis found that at 10-12 months infants' receptive vocabulary was associated with their right-hand bias for imperative points. This association has also been found in both younger and older infants. For example, 18-28 week old infants show an increased in right-handed shaking actions, when they begin to babble. (Locke, Bekken, McMinn-Larson & Wein, 1995). Also, around the age that children reach the lexical spurt, they also become more right-handed for pointing (Cochet, Jover & Vauclair, 2011).

Although the relation between language development and gesturing has been shown in childhood and adulthood, there is currently a lack of literature investigating the relationship between vocabulary development and gesture handedness outside of infancy. The current paper will address this missing literature. The current paper investigates how gesture handedness and performance in a verb generalization task are related.

Current study

The current study will address some of the questions about gesture handedness and later language development by reanalysing data from a previous study (Chapter 4). In that study, children were taught novel verbs, using video exemplars. Children then had to extend these verbs on either the basis of the sameness of the end state (change-of-state verb interpretation) or manner (manner verb interpretation). Children were required to point to their choice. In the original study, which hand children used to responded with, was noted down, although it was not analysed. The current study investigates these data more closely.

We hypothesise that speech-gesture integration (as assessed by generalisation of the verb in a way consistent with the gesture seen) will be associated with right-handed responses. This is due to the overlap between the areas controlling speech-gesture integration and gesture production in the left hemisphere.

Method

Participants

One-hundred-and-twenty 3-year-old children participated in the original study (57 females and 63 males; *M*= 41.48 months, *SD*= 3.13). Children were recruited from and tested in their own nurseries, across Warwickshire, England. Children received a sticker in return for their participation. There were no differences in ages (measured in months) between the gesture conditions.

Children were pseudo-randomly assigned into one of three gesture conditions (no iconic gesture, manner gestures, and end state gestures). This was such that children were assigned into a group before the experimenter met them, for example working down an attendance list or the order in which consent forms were given to the experimenter. The 19 children who were excluded from the original study were also excluded from this study. As the current research question relates to speech-gesture integration and gesture handedness, the data from children in the no gesture group was not used in the current reanalysis. Thus, the final sample came from 68 children (end state gesture group- 32, manner gesture group- 36) (31 females and 37 males; *M*= 41.51 months, *SD* = 3.12).

As the original study was not investigating handedness, handedness measures were not taken from the children.

Summary of method

As this is a reanalysis of the data from the experiment described in Chapter 4 details of the method can be found in the previous chapter. To briefly summarise, the study used short video clips each depicting an actor's hand manipulating objects using a particular manner to bring about a particular end state. See Appendix 4 for details.

During a training phase, children saw one video and were taught a novel verb (e.g. '*Look, she's novel-verb-ing it*'). The novel verbs *Dax*, *Larp*, *Stum*, *Tood* and *Blick*. During the training phase, children in the end state gesture condition saw the experimenter produce a gesture depicting the end state of the scene (e.g. a cloud shape), while children in the manner gesture condition produce a gesture depicting the action of the hand in the video (e.g. placing an object in position). A pre-test revealed that children could match gestures to the video referents better than chance (M = .660, SD = 0.145, $t(13)$ = 4.137, p=.001) and the performance did not significantly differ between end state and manner gestures (χ^2 (1) = 0.154, p>.1). See Appendix 6 for details. Half of the end state gestures the experimenter produced were bimanual, and half were uni-manual (right-handed). All of the manner gestures used were uni-manual (right-handed).

During a test phase, children saw two videos playing simultaneously, side-by-side. One video showed the same action resulting in a different end state and the other showed a different action resulting in the same end state. Children were asked '*which one is novel-verb-ing?*' Children were required to point to their chosen video. The choice that they made, as well as the hand used to point with, were noted down in real time by the experimenter.

Results

Excluded

Two trials from two children (one per child) were excluded from the analysis. One as the child pointed bimanually and the other as the child did not make a choice.

Summary of original findings (from Chapter 4)

The report of the original study showed that, overall, children who saw manner gestures were more likely to select the video consistent with a manner interpretation than either of the other two gesture groups. There was no difference in performance between children who saw end state gestures as well as those who saw no gestures.

Comparison of hand choice between gesture consistent and inconsistent responses

The data from children in the manner and end state gesture conditions were collapsed. Only the data from children who selected a gesture consistent and gesture inconsistent response at least once during the experiment were entered into the first analysis (N= 62). The independent variable was whether the response was consistent with the gesture that child had seen or not on a given trial. Thus, children in the manner gesture group were coded as gesture consistent if they selected the same manner video and gesture inconsistent if they selected the same end state video, and the reverse was true for children in the end state gesture condition. The dependent variable was which hand children used to respond (left or right). As the dependent variable was binary the data were analysed using a generalised linear mixed effects model. See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013).

In order to assess whether there was an effect of selecting a gesture consistent response on hand choice two models were compared. The first model included gesture consistency (consistent or not) as the fixed effect. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for gesture consistency, 3) correlations between the random intercept by participant and the random slope by participant for gesture consistency. The second model only included a constant and the same random effect structure.

The result of a likelihood ratio test revealed there was a significant effect of gesture consistency on hand choice (χ^2 (1) = 6.259, p=.012). This is such that when children selected the video which was consistent with the gesture they had seen at training, they were more likely to use their right hand. See Figure 7.1 for the descriptive results. Table 7.1 reports the parameters of the model with gesture consistency as a fixed effect (Model 1).

Table 7.1

Fixed effects of Model 1 (fixed effect of gesture consistency)

	B	*SE*	*z*	*p*
Intercept	1.065	0.335	3.181	.001
Gesture Consistency	1.419	0.435	3.259	.001

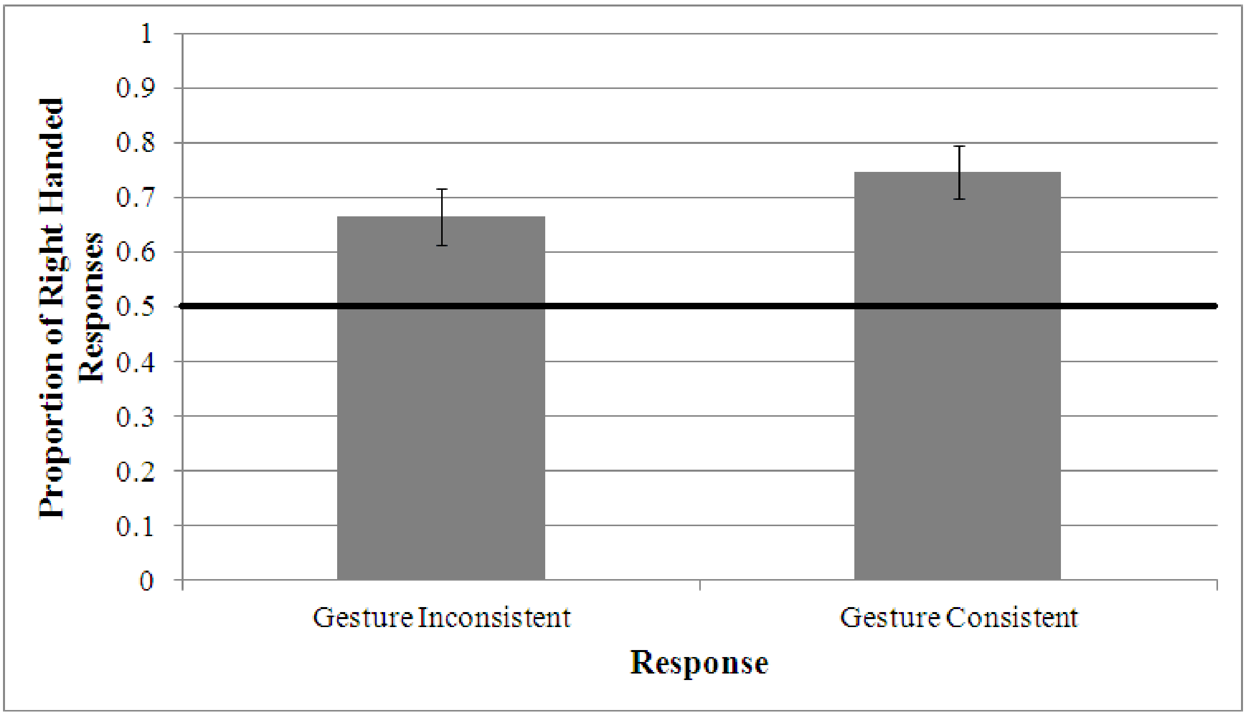


Figure 7.1. The proportion of right-handed gestures, when children selected the gesture consistent and inconsistent videos. The thick line represents chance (0.5) and the error bars represents standard error of participant means.

Comparison of performance between hands

Note that as the relationship between gesture consistency and hand choice was observation (we did not manipulate either variable), the analysis was then rerun using gesture consistency as the dependent variable and hand choice as the independent variable. Only the data from children who used both of their hands at least once during the experiment were entered (N=30).

In order to assess whether there was a main effect of hand two models were compared. The first model included the fixed effect of hand (left and right). The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for hand, 3) correlations between the random intercept by participant and the random slope by participant for hand. The second model only included a constant and the same random effect structure.

The results of a likelihood ratio revealed a marginal effect of hand on gesture consistent (χ^2 (1) = 3.299, *p*=.069). Note that this change in significance may be due to the lack of power compared to the first analysis because N decreased from 62 to 30. The result indicates that when children used the right hand, they were more likely to respond consistently with the gesture they had seen in training. See Figure 7.2 for the descriptive results. Table 7.2 reports the parameters of the model with hand choice as a fixed effect (Model 2).

Table 7.2

Fixed effects of Model 2 (fixed effect of hand choice)

	B	*SE*	*z*	*p*
Intercept	-0.148	0.272	-0.544	.587
Hand Choice	0.625	0.346	1.809	.071

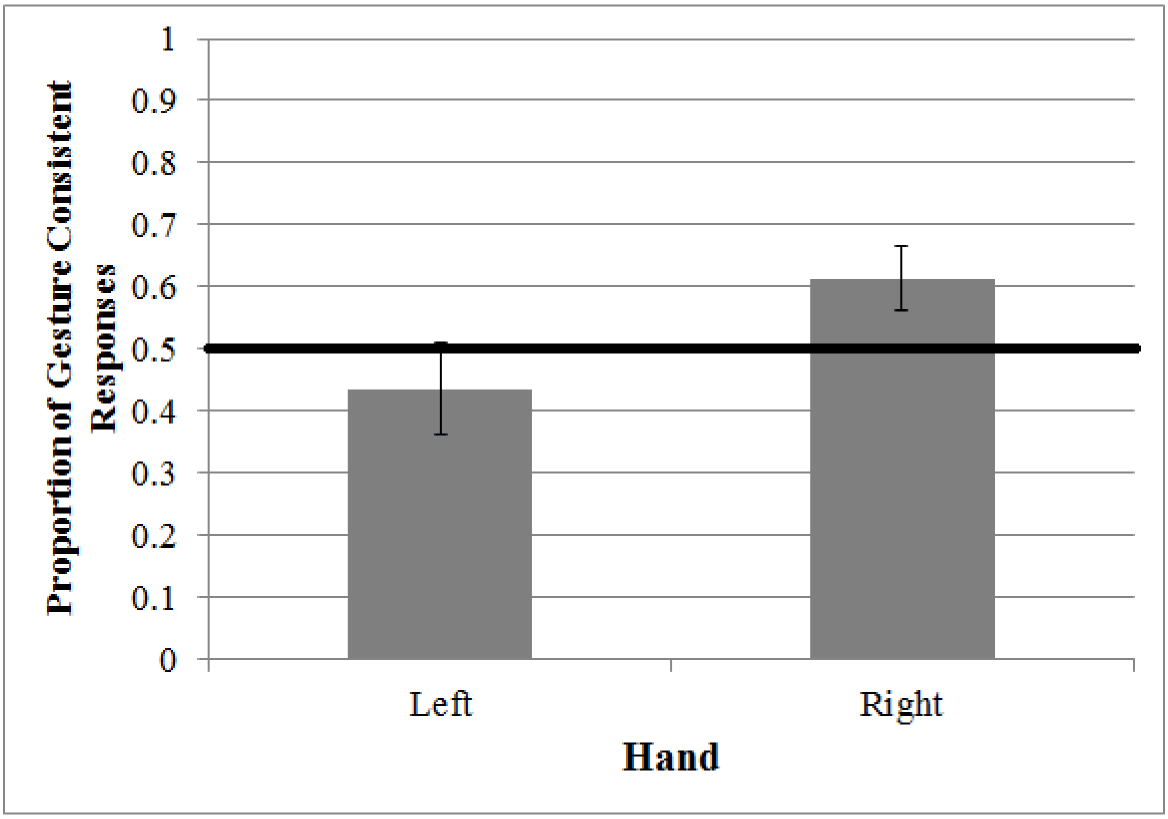


Figure 7.2. The proportion of gesture consistent responses, when children used the left and right hand. The thick line represents chance (0.5) and the error bars represents standard error of participant means.

Comparison to chance

The results for the two hand groups were then compared to chance (0.5) using planned t-tests. The results showed that, when children used their right hand they selected the gesture consistent choice more often than chance (t (29) = 2.196, p=.036). In contrast, when children used their left hand, there performance did not differ from chance level (p>.1).

Comparison of handedness when seeing bimanual and uni-manual end state gestures

The association demonstrated above between right-handed responses and gesture consistent responses, may be due to the left hemisphere's dominance in speech-gesture integration processing (Willems, Özyürek & Hagoort, 2007), as well as this hemisphere's ability to produce right sided movements.

However, one alternative account may suggest that this relationship occurs since the experimenter herself was right-handed. If children were engaged with the experimenter this could have two effects: 1) children imitated the experimenter's handedness pattern, 2) children incorporated the information from the gesture into their representation of the word. This could therefore drive the observed association.

In order to address this issue the data from the end state group was analysed further (N=32). This was because in half of the end state gestures, the experimenter used both hands (e.g. square, circle) and in the other half she used only her right hand (e.g. U, wavy line). This provides an opportunity to investigate whether seeing uni-manual, right-handed gestures influences children to give more right-handed responses, compared to seeing bimanual gestures.

The dependent variable was the hand children used to respond, and the independent variables were how many hands the experimenter used and whether children selected the gesture consistent (same end state) video. In order to rule out the alternative explanation the interaction between the two independent variables was critical. If it is true that children's attention to the experimenter influences their hand choice and their response, a significant interaction would be predicted, such that the influence of the experimenter's hands is larger when children have responded consistently with the gesture they have seen, than when they respond inconsistently.

In order to test for this interaction, two generalised linear mixed effects models were compared. The first model included the following fixed effects: the number of hands the experimenter used (one or two), whether or not children's response was consistent with the gesture (consistent or not) and the interaction between the two. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for number of experimenter's hands (but not for gesture consistent, since not all children responded both consistently and inconsistently) 3) correlations between the random intercept by participant and the random slope by participant for number of experimenter's hands. The second model was the same as the first except that it did not include the interaction between the two fixed factors.

The results of a likelihood ratio test revealed that there was no interaction between the experimenter's hands and children's responses on their hand choice (p>.1). In other words, when children selected the same end state video, their hand choice was not more influenced by the experimenter's hands than when they did not select the same end state video. See figure 7.3 for the descriptive results. Table 7.3 reports the parameters of the model with gesture consistency and the number of hands used by the experimenter as fixed effects but not the interaction between the two (Model 3).

Table 7.3

Fixed effects of Model 3 (fixed effects of gesture consistency and number of hands used by the experimenter)

	B	*SE*	*z*	*p*
Intercept	3.112	0.924	3.370	.001
Number of hands used by the experimenter	-1.407	0.663	-2.123	.034
Gesture Consistency	0.664	0.618	1.075	.283

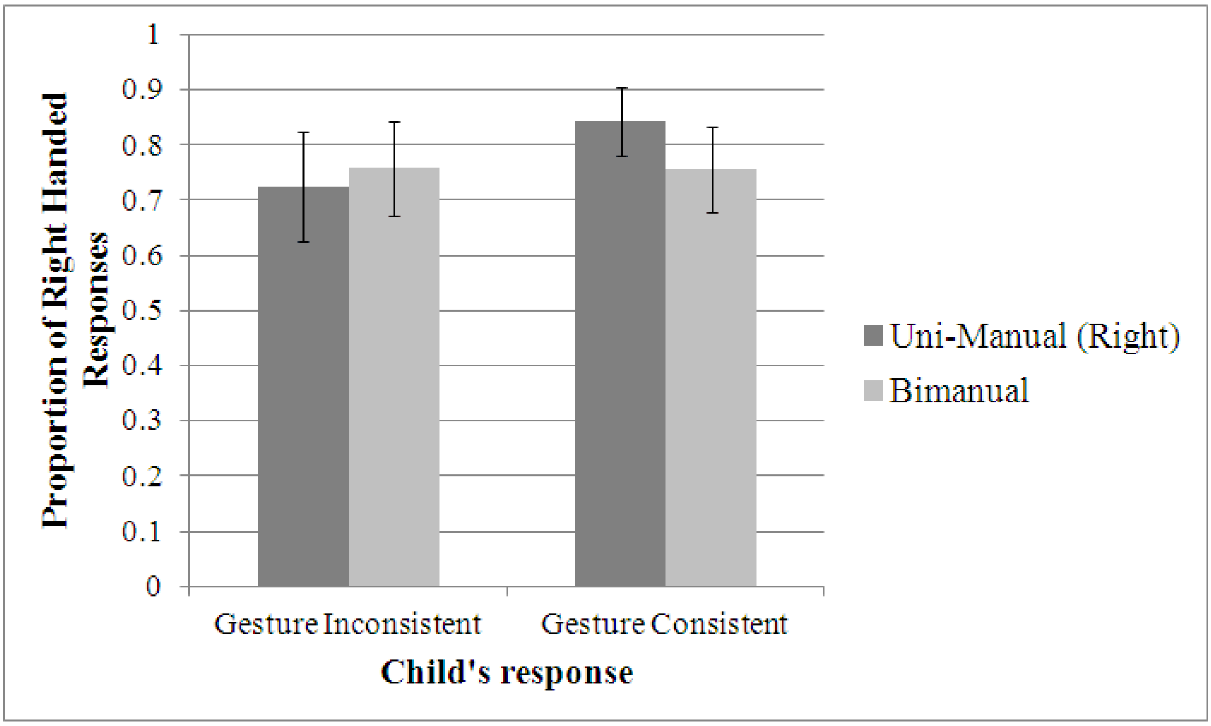


Figure 7.3. The proportion of right-handed responses made by children in the end state gesture condition, when the experimenter produced one or two handed gestures and when they selected the same end state video. The error bars represent the standard error of the participant means.

Finally, in order to investigate whether there was a main effect of the experimenter's hands on children hand choice two more models were compared. The first model included the number of experimenter's hands (one or two) as the fixed factor. The model also included random intercepts by participants, random slopes by participants for the number of experimenter's hands, and the correlation between the random intercepts by participant and the random slopes by participants for the number of experimenter's hands. The second model included a constant and the same random factor structure as the first.

The results of a likelihood ratio test showed that the number of hands used by experimenter did not influence the hand choice of participants ($p>.1$). See Figure 7.4 for the descriptive results.

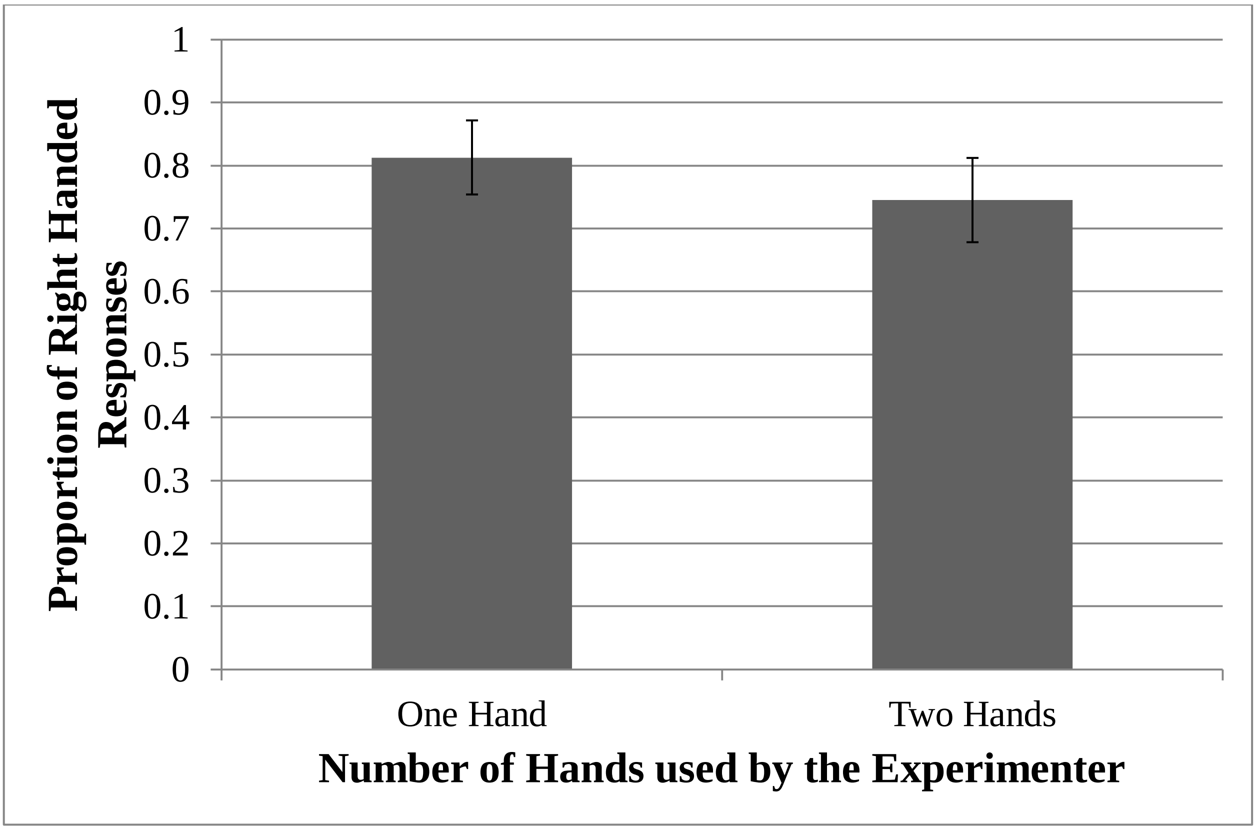


Figure 7.4. The proportion of right-handed responses made by children in the end state gesture condition, when the experimenter produced one or two handed gestures. The error bars represent the standard error of the participant means.

The current set of analysis found no evidence that children were more likely to use their right hand if they saw the experimenter produce a right-handed uni-manual gesture. Thus it appears that the relationship between gesture consistent responses and right-handed responses is not due to the handedness patterns of the experimenter.

Discussion

The current study investigated the relationship between gesture handedness and performance in a verb generalisation task. The results show an association between right-handed pointing responses and selecting the video consistent with the gesture they had seen (i.e. children in the manner gesture condition selected the same-manner choice more often and the reverse was true for children in the end state gesture condition). The results from the original study (Chapter 4) found that information from gesture appears to be integrated into the word learning process. The results of the current study extend this by suggesting that for 3-year-olds using the right hand to respond in a verb learning task, is associated with a representation of a novel verb that has incorporated information from speech and gesture. This may be because speech-gesture integration is typically left lateralised (Willems et al., 2007)

It must be noted that the data presented in the current study were observational, which limits the conclusions that can be drawn. As gesture handedness was not manipulated, the cause of the observe trend cannot be concluded. In other words, it remains unclear if responding in the direction of the gesture leads to right-handedness, or using your right hand leads to choosing the answer consistent with the gesture at training (both possibilities are discussed below). Further, as gesture handedness was not manipulated in the current study, there were unequal numbers of left and right gestures.

Why was right gesture handedness associated with better speech-gesture integration?

We now consider different possible, speculative reasons for the observed effect. It should be noted that these are not mutually exclusive of each other and could co-occur.

The first possibility is that the right hand has privileged access to the integrated representations of a new word. Speech-gesture integration typically occurs in the left hemisphere, including Broca's area (e.g. Willems et al., 2007). As this information is processed in the left hemisphere, information does not need to travel as far to reach the motor areas controlling the right hand compared to the left. Further, as this activation does not need to spread as far, the information reaching the areas controlling the right hand will be less noisy than that having to travel across the corpus callosum to areas controlling the left hand. Therefore, the right hand has better access to the representation compared to the left, leading to children making more choices in line with the gesture they had seen.

Further, it is also possible that efficient speech-gesture integration leads to more right-handed gesturing. When children are asked to generalise a word, they may rely more heavily on representations when these representations are stronger (e.g. through the incorporation of information in gesture). When they then call upon this representation to respond in the task, the left hemisphere becomes more active and this results in a right-hand response. In other words, when gesture is integrated into the representation of the word, more right-handed gestures are produced. In contrast, when speech-gesture integration during verb learning is not efficient, the representation is weaker. This could result in fewer choices in the direction of the gesture, and also this fewer right-handed gestures, since the left hemisphere representation was not used as much.

The second account is the reverse of the first. Specifically, if children begin to respond with their right hand (before they have decided on their choice), the action may increases activation in the left hemisphere, where speech-gesture integration occurs. This boost in activation could help children to access the integrated representation, such that they select more choices consistent with the gesture they saw at training.

What was the influence of seeing the experimenter use uni- or bimanual gestures?

The two possible accounts already discussed, assume that seeing types of the experimenter's iconic gestures influenced gesture handedness and integration together. It is possible, however, that attention to the experimenter's gestures may have influenced both children's hand choice and verb interpretation separately. For example, Kimbara (2008) found that during conversations adults will converge on similar hand shapes when talking about particular entities. This shows how the speaker's gestures can influence the listener's gestures. By a similar mechanism, it may be possible that children's hand choice can be influenced by the hand choice of the speaker. If children paid close attention to the experimenter's gestures they may be more likely to incorporate the information into the novel verb's representation. Further children may imitate the experimenter's gestures (which were either right-handed or bimanual). Thus, paying attention to these gestures may lead to more imitation and an increase in the use of the right hand. This would mean that when children paid close attention to the experimenter's gestures they were more biased in favour of the interpretation depicted and they were more right-handed, and the reverse would be found when children paid less attention to the experimenter's gestures.

However, in the final analysis, it was found that children's handedness was not affected by seeing right-handed or bimanual gestures. This suggests that children were not simply imitating gestures, or an increase in right hand use would have been found in the uni-manual conditions. Thus, the current results support the idea that speech-gesture integration in the left hemisphere and the use of the right hand to respond, are associated directly in a verb learning task.

Implications

The results of the current study may have important practical implications. For example, if right-handed gesturing can encourage more efficient speech-gesture integration, this could be potentially be integrated to other teaching techniques to improve word learning abilities, since seeing gestures is related to word learning (e.g. the study in Chapter 4; McGregor et al., 2009). This may be particularly important for children struggling to acquire a language, or those acquiring a second language. However, far more research would be needed to understand if encouraging right-handed pointing is useful, especially given the lack of a baseline condition in the current study.

The results also have important theoretical implications and can support theories of gesture-speech integration in the left hemisphere.

General conclusions

This paper reports the reanalysis of a previous experiment (Chapter 4), incorporating information about the hand that children used to respond, which was not reported in the original study. The results showed that when children responded with their right hand they showed an increased bias in the direction of the gesture seen at training. Although speculative, the current results support the idea that speech-gesture integration processes, occurring in the left hemisphere are associated with gesture handedness in a linguistic task.

Chapter 8 will extend the current study by manipulating the hand that children use to respond in a verb generalisation task.

CHAPTER 8

INFLUENCE OF GESTURE HANDEDNESS ON WORD LEARNING AND MEMORY

8.1. Goals and motivations

In Chapter 7 we found that children performed differently in the verb learning task when they used different hands to respond. As the purpose of the study that these data came from did not manipulate handedness, it remains unclear whether children's responses influenced their hand choice or their hand choice influenced their responses.

From previous research we know that children's own gesturing can influence language learning (Tellier, 2008) and that there is a relationship between gesture handedness and vocabulary development (e.g. Cochet, Jover & Vauclair, 2011). Chapter 6 of the current thesis found that there a correlation between pointing handedness and receptive vocabulary development as young as 10-12 months. Although there are many studies now showing an association between right-handed gestures and vocabulary development, since these studies used observational data, the nature of this relationship remains unclear.

The current study aimed to investigate this relationship further by manipulating gesture handedness (pointing), such that directionality of this relationship can be explored. The current study manipulated children's hand choices while they responded in either a linguistic (verb learning) or non-linguistic (memory) task. The study investigated whether using the right hand in a linguistic task can improve performance, while having no effect during a non-linguistic task.

If children's language acquisition can be improved by right-handed gesturing, this may have practical implications in teaching and therapy contexts.

8.2. ARTICLE 5

ENCOURGAING RIGHT-HANDED POINTING SHOWS A LINGUISTIC ADVANTAGE OVER LEFT-HANDED POINTING

Abstract

Research has shown a strong association between language development and right-handed gesturing (e.g. Cochet, Jover & Vouclair, 2011; Esseily, Jacquet & Fagard, 2011). The current study investigated whether manipulating the hand with which children were allowed to use in pointing tasks, would affect their performance. In either a verb learning task (linguistic) or a memory task (non-linguistic), 3-year-old children were instructed to use either their left or right hand to respond. While hand choice had no effect on performance in the memory task, using the right hand showed a significant advantage over using the left hand in the verb learning task. The results are the first to suggest that manipulating hand choice for gesturing may be able to influence the performance of a linguistic task.

Key words: Gesture, handedness, language acquisition, word learning, lateralisation.

Speech accompanying gestures are found in all cultures in the world and are a key part of human communication (e.g. Liszkowski, Brown, Callaghan, Takada & de Vos, 2012). Gestures can help speakers to organise their thoughts (Kita, 2000) and can help listeners understand messages more clearly (e.g. McNeil, Alibali & Evans, 2000). Gestures are also used in many language and cognitive assessments. For example, several tasks in the Mullen scale of Early Leaning (Mullen, 1995) and language assessments (such as the British Picture Vocabulary Scale) include pointing to stimuli. It is, therefore, very important to understand how these gestures may influence children's performance on such assessments.

Gesture can influence linguistic processes. For example, gesturing has been shown to help speakers recall or retrieve words when they are in a tip-of-the-tongue state (adults: Frick-Horbury & Guttentag, 1998; children: Pine, Bird & Kirk, 2007) and prohibiting gesturing can result in less fluent speech (Rauscher, Krauss & Chen, 1996). Furthermore, the production of gestures influences the content of speech, in comparison to when gestures are prohibited. When participants gestured during explanation of metaphorical phrases, they provided fuller explanations of metaphorical mapping (Argyriou & Kita, 2013). Gesturing has also been shown to influence syntactic processing (Mol & Kita, 2012). Thus, gesturing has a clear impact on many levels of linguistic processing.

Gesturing has also been shown to influence language learning (e.g. McGregor, Rohlfing, Bean & Marschner, 2009). For example, from a young age children are able to use gestures to map a novel verb to a novel scene (Goodrich & Kam, 2009). Further, chapter 4 of the current thesis found that 3-year-olds are able to use the gestures of a speaker to pinpoint the reference of a novel word within a complex scene. Furthermore, seeing gestures can help children to build a more robust and abstract representation of new words (McGregor et al., 2009).

As reviewed above, gesture production can influence cognition and language processing. It remains unclear, however, whether using the right hand in particular may facilitate language learning. Such a right-hand advantage is expected due to the overlap of neural substrates for speech and gesture processing in the left hemisphere in both comprehension (e.g. Skipper, Goldin-Meadow, Nusbaum & Small, 2007; Willems, Özyürek & Hagoort, 2007) and production (e.g., Kimura, 1973a).

Although right-handed gesturing and vocabulary development are associated with each other (e.g. Chapter 6 of the current thesis; Cochet, Jover & Vauclair, 2011; Esseily, Jacquet & Fagard, 2011; Vauclair & Imbault, 2009), unless gesture handedness is manipulated, it remains unclear whether right-handed gesturing leads to more efficient language learning and thus a larger vocabulary, or if a larger vocabulary leads to right-handed gesturing.

Gesture production is influenced by which hemisphere is dominant in controlling language (Kimura, 1973a, 1973b). Thus, even left-handed individuals (whose language is lateralised to the left hemisphere) show more right-handed gesturing than would be expected from their manual handedness alone (1973b). Furthermore, when adults speak metaphorically this right-hand gesture bias is attenuated (Kita, de Conappa & Mohr, 2007). This is because producing metaphorical speech activates the right hemisphere (e.g. Taylor & Regard, 2003), which triggers left-handed gestures and weakens the right-hand gesture bias. Finally, when adults are only able to gesture with their left hand their speech contains more metaphorical content than when their right hand is available (Argyriou & Kita, 2013).

Current study

The current study investigated whether using the right hand to respond in a linguistic task shows an advantage in children's performance, compared with the left hand. This is because the right hand's movements are controlled by the left hemisphere, which is typically dominant for language processing (e.g. Knecht, Drager, Deppe, Bobe, Lohmann, Floel et al., 2000).

In the current study cerebral dominance for language was not measured, but it is assumed that most of the right-handed participants will be developing left-lateralised language even at this young age (Holowka & Petitto, 2002; Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002).

To rule out the possibility that any differences in performance between right and left hand groups is due to dexterity (children may be more comfortable using their right hand compared to their left), a non-linguistic control task (episodic memory task) was used. This condition should not reveal any hand advantage, as this type of memory is thought to be processed bilaterally (e.g. Ofen, Chai, Schuill, Whitfield-Gabrieli, & Gabrieli, 2012).

In the linguistic task, children will be taught novel manner of motion verbs, and then asked to generalise them to either the same person doing a different action (incorrect), or a different person doing the same action (correct). Research has shown 3-year-olds typically struggle with this decision (e.g. Imai, Haryu & Okada, 2005; Kantartzis, Imai & Kita, 2011, Kersten & Smith, 2002).

In the memory task, children will be shown videos from the same set of stimuli as the verb learning task. They will then asked which one they had seen previously, either the identical video (correct), or the same actor performing a different action (incorrect).

In both tasks, children will be asked to respond using pointing gestures made with either their left or right hand. We predict an interaction between task and hand, such that there will be a right-hand advantage in the verb learning task but no differences between hands in the memory task.

Method

Participants

One-hundred-and-sixty 3-year-olds (62 females, 98 males, *M* = 41.7 months, *SD*= 3.27) took part in the study. Participants were recruited from nurseries in Warwickshire and the surrounding area in England. Participants were tested individually in a quiet corner of their own nursery and received a sticker in return for their participation.

Seven of the children included in the study were thought to be multilingual but their English was good and they successfully completed the practice trials. Other children were all English monolingual speakers.

Children were pseudo-randomly assigned into one of the hand and task conditions (both manipulations were between subjects). This was such that children were assigned into a group before the experimenter met them, for example working down an attendance list or the order in which consent forms were given to the experimenter, whilst taking care to balance groups, (e.g. in terms of sex). Each condition had an equal number of male and female participants, and there were no differences in age (measured in months) between condition (p>.1).

Twenty-nine children were excluded from the analysis for various reasons, see Appendix 9. Importantly, children were excluded if they were coded as left-handed in both manual handedness tasks. Therefore the final data set came from 131 children: 32 in the memory task- right-hand condition, 30 in the memory task- left-hand condition, 33 in the verb learning task- right-hand condition and 36 in the verb learning task- left-hand condition.

Stimuli

The stimuli used in the study were the same for both the verb learning and the memory task. The stimuli were taken from Mumford and Kita (2010) and were made up of 28 video clips, ranging from 4-8 seconds each. All the video clips depicted a male or female actor performing unusual manners of locomotion to get from one side of the screen to the other. The direction of movement was balanced, such that half of the time actors went from left to right, and other times went right to left. Four male actors and three female actors were used.

The 28 video clips were organised into seven groups containing four video clips each: a male and female actor each performing two different manners. For full details of the actions used, see Appendix 10. The two actors in a group performed the action similarly to each other, such that the same verb could be applied to both video clips. Stimuli were presented to the participants on a 20” screen.

The seven novel verbs taught were dax, larp, blick, tood, stum, pim and krad.

Procedure

Manual handedness tasks

Before the gesture manipulation was introduced, all of the children took part in two short tasks to assess their manual handedness. Firstly, children were asked to retrieve a small ball from a cylindrical contained with a lip loosely screwed on. The dominant hand was the one used to hold the lip while unscrewing it. Secondly, children were asked to draw a circle on a page. For both tasks, the stimuli were set up before children arrived at the table for testing and were presented at the midline of the child.

Pointing handedness manipulation

Before the practice trials began, children were told that they needed to hide one of their hands and to do this they should put it behind their back (demonstrated by the experimenter). Children were reminded of this instruction throughout the study, and it was noted if they ever forgot and responded with the other hand.

Practice trials

There were four practice trials in total, for which the stimuli used for all children was identical. The practice trials were designed to boost confidence and familiarise the children with the pointing procedure. In the first three practice trials children were asked to point to familiar objects. In the final practice trial, children were familiarised with the structure of the main experiment. First, children were shown a video of a woman running. Children in the verb learning condition heard the sentence '*look, she's running*' and children in the memory condition heard the sentence '*wow, look at him!*' Children were then shown the same video again and a video of a man jumping. Children in the verb learning condition were asked '*which one's running?*' and children in the memory task were asked '*which video is the same as before?*'

Experimental trials

Verb learning

At the start of the experiment, children were told that the experimenter was going to teach them some new words. Children were then taught seven novel verbs (one per trial). Each trial consisted of two stages: training and test. Test occurred immediately after training, before moving on to the next trial. During training, children saw either a man or a woman moving in a novel manner. They were told: '*look, s/he's NOVEL VERB-ing!*' The video and the training sentence were then repeated. At test children saw two videos playing simultaneously, side-by side and were asked '*which one is NOVEL VERB-ing?*' One video depicted the same actor now performing a different action (incorrect) and the other depicted a new actor performing the same action as in training (correct). Children were required to point to their choice.

Memory

The memory task followed the same structure as the verb learning one, using the same set of 28 videos. During the training phase, children were told '*wow, look at him/ her*'. The video and the training sentence were repeated. At test, the two videos differed from the ones in the verb learning task. Children saw the identical video (correct) and a video of the same actor now performing a different action (incorrect). Children were asked, '*which video is the same as before?*' and were required to point to their choice.

In both conditions, if children tried to point to both videos at test, they were reminded they could only pick one and the question was repeated. Children's final choice, indicated by a pointing gesture, was noted down by the experimenter.

Experimenter location

For half of the children the experimenter sat on the right of the participant and for the other half she sat on the participant's left.

Results

Exclusions and dependent variable

We excluded the following trials from the analysis. In 57 trials (from 39 participants, range 1-3 trials per child) participants responded using either the incorrect hand or both hands. In one other trial the child selected a video before they had started to play. On three trials from three children (one trial per child), children did not select a video. The dependent variable was binary either correct or incorrect, on each trial.

Were performances in the tasks influenced by which hand was used?

As the dependent variable was binary, the data was entered into a generalised linear mixed effects model See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013).

In order to test whether there was an interaction between task and hand conditions, we compared two models. The first model included the following fixed effects: task, hand and the interaction between task and hand. The model also included random intercepts by participant. The second model had only the two main effects (task and hand) but did not include the interaction between task and hand. This model also included random intercepts by participant.

Comparison of the two models using a likelihood ratio test showed that the interaction was marginally significant (χ^2 (1) = 2.964, *p*=.085). See Figure 8.1 for the descriptive results. Table 8.1 reports the parameters of the model including the main effects of hand and task and the interaction between the two (Model 1).

Table 8.1

Fixed effects of Model 1 (fixed effects of hand, task and the interaction between the two)

	B	*SE*	*z*	*p*
Intercept	0.824	0.224	3.683	<.001
Task	-0.923	0.294	-3.104	.002
Hand	-0.141	0.306	-0.462	.644
Task* Hand	0.733	0.417	1.759	.079

Note, the memory task was the reference group for task, and the left-hand condition was the reference group for hand. So the effect of task refers to the effect of task within the left-hand condition, and the effect of hand refers to the effect of hand within the memory condition.

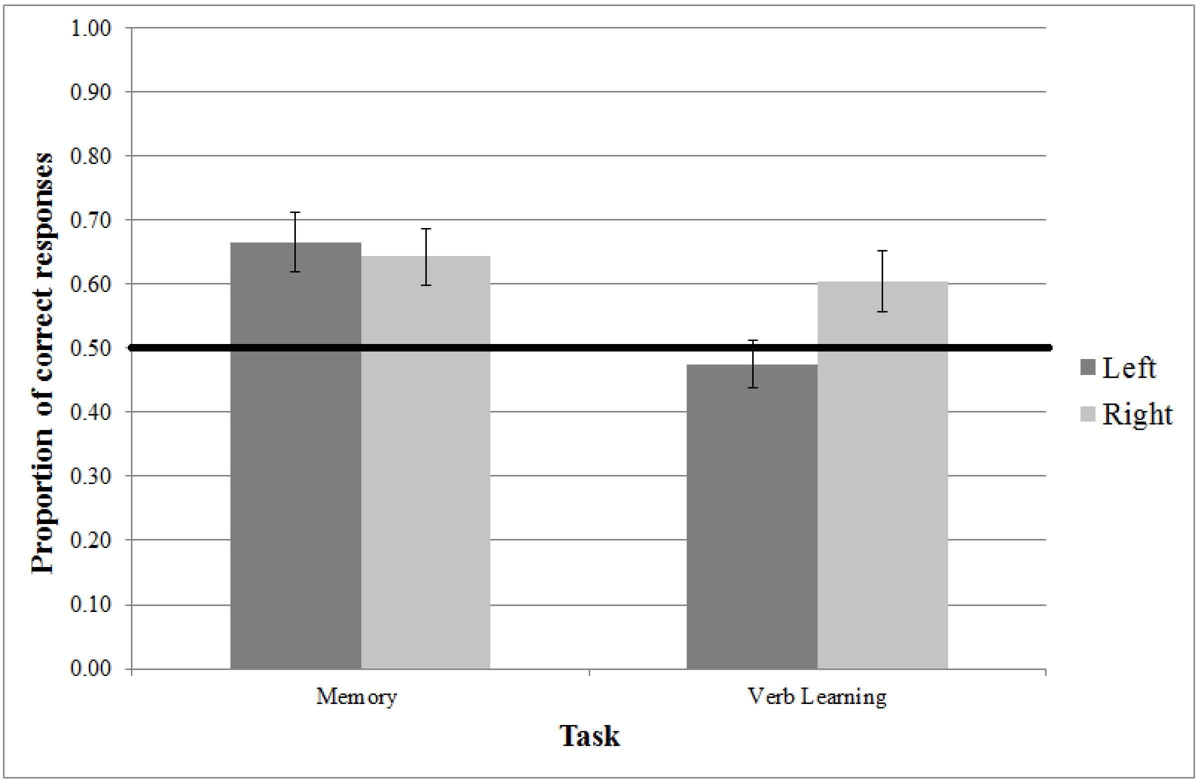


Figure 8.1. The average proportion of correct responses in the memory and verb learning tasks, completed with the left and right hands. The thick line shows chance (0.5) and the error bars represent standard error of the participant means.

In order to test whether there was a main effect of task two additional models were compared. The first model included task as a fixed effect and random intercepts by participant. The second model only included a constant and random intercepts by participant. The results from a likelihood ratio test revealed that there was a significant main effect of task (χ^2 (1) = 6.839, *p*=.009). This was such that children in the memory task performed better than children in the verb learning task. Table 8.2 reports the parameters of the model including the main effect of task (Model 2).

Table 8.2

Fixed effects of Model 2 (fixed effect of task)

	B	*SE*	*z*	*p*
Intercept	0.755	0.155	4.854	<.001
Task	-0.566	0.211	-2.679	.007

In order to test whether there was a main effect of hand two additional models were compared. The first model included hand as a fixed effect and random intercepts by participant. The second model only included a constant and random intercepts by participant. The results from a likelihood ratio test revealed that there was no main effect of hand (χ^2 (1) = 1.658, *p*>.1).

The data were split the data by task and planned comparisons were conducted to see whether there was an effect of hand within the two task groups.

From the data of children in the memory task we compared two models. The first model included hand as a fixed effect and random intercepts by participant. The second model only had a constant and random intercepts by participant. The two models were compared using a likelihood ratio test. The results revealed that there was no difference between the models (χ^2 (1) = 0.191, *p*>.1). Therefore, the model can predict correctness equally well using an overall mean as using a mean from each hand group.

Next from the data of children in the verb learning task two more models were compared. As with the memory comparison, the first model included hand as a fixed effect and random intercepts by participant. The second model only had a constant and random intercepts by participant. The two models were compared using a likelihood ratio test. The results revealed that there was a significant difference between the models (χ^2 (1) = 4.523, *p*=.033). Therefore, the model can predict correctness significantly better if it uses means from each hand, as compared to using an overall mean. . Table 8.3 reports the parameters of the model including the main effect of hand (Model 3).

Table 8.3

Fixed effects of Model 3 (fixed effect of hand)

	B	*SE*	*z*	*p*
Intercept	-0.097	0.183	-0.531	.596
Hand	0.575	0.263	2.185	.029

Comparison to chance

Next, the data were compared to chance (0.5). The results showed that in the memory condition, both hand groups performed better than chance (right: *t* (31) = 3.160, *p*=.004; left: *t* (30) = 3.540, *p*=.001). In contrast, in the verb learning task, children using their right hand performed better than chance (*t* (32) = 2.146, *p*=.040), but children using their left hand performed at chance level (*p*>.1).

These results indicated that responding with the right hand shows an advantage over the left hand in a language task, but not on a non-linguistic task. The poorer performance of the left-hand condition in the linguistic task is unlikely to be due to dexterity, that is, distraction due to not being able to use the more dexterous right hand. This is because the performance of the non-linguistic memory task was not affected by the hand manipulation.

Is the influence of hand in the verb learning task due to the higher difficulty of this task?

As children's performance differed between tasks, it is not clear whether the effect of the hand used in response in the verb learning task was due to its linguistic content or to its difficulty. It is possible that when children found the verb learning task difficult, the added burden of using the non-dominant hand hindered performance.

To rule out the explanation based on difficulty, we used a subset of children who found the two tasks equally difficult. To do this we excluded the data from the top child in each hand group who performed the memory task, and the bottom child in each hand group who performed the verb learning task, and reran the analysis. This was repeated until there was no significant effect of task. This resulted in excluding two children per group (eight in total). The descriptive results can be seen in Figure 8.2.

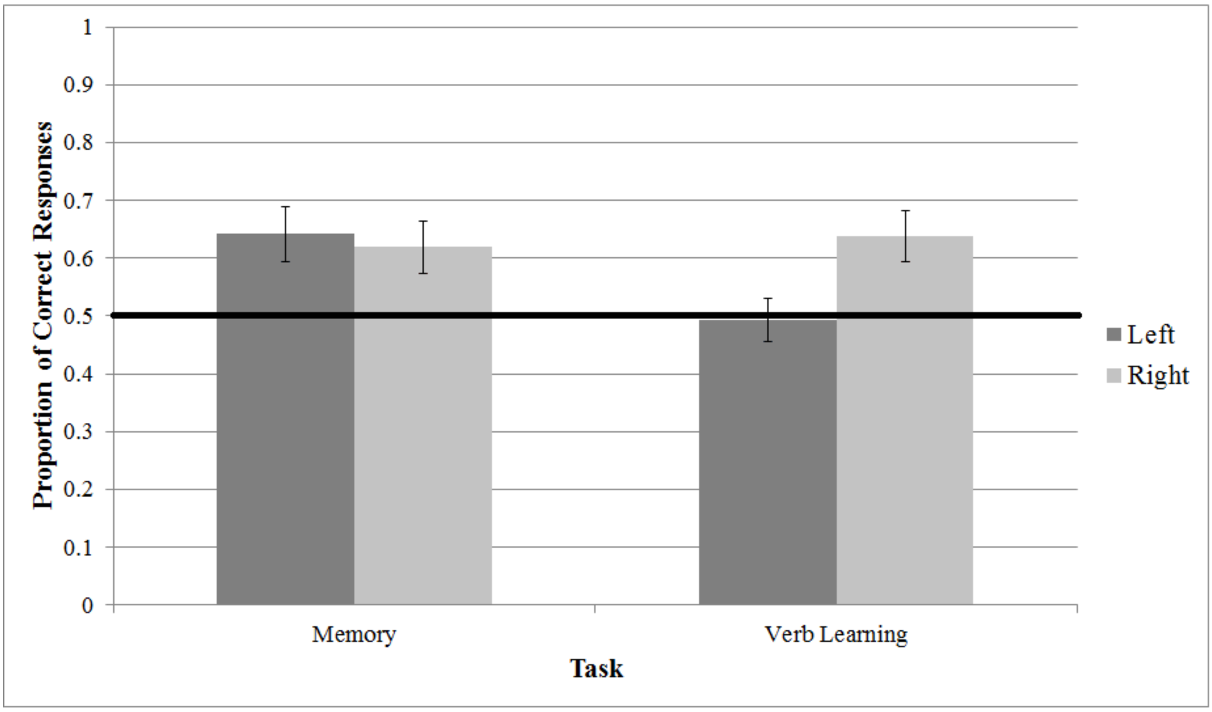


Figure 8.2. The average proportion of correct responses in the memory and verb learning tasks completed with the left and right hands, using a sample of children to control for task difficulty. The thick line shows chance (0.5) and the error bars represent standard error of the participant means.

The interaction was then tested again by comparing two models using this subset of the data. The first model included the following fixed effects: task, hand and the interaction between task and hand. The model also included random intercepts by participant. The second model had only the two main effects (task and hand) but did not include the interaction between task and hand. This model also included random intercepts by participant. Comparison of the two models using a likelihood ratio test showed that the interaction between task and hand group was significant (χ^2 (1) = 3.845, p=.050). Table 8.4 reports the parameters of the model including the main effects of hand and task and the interaction between the two (Model 4).

Table 8.4

Fixed effects of Model 4 (fixed effects of hand, task and the interaction between the two)

	B	*SE*	*z*	*p*
Intercept	0.665	0.206	3.219	.001
Task	-0.673	0.275	-2.449	.014
Hand	-0.131	0.282	-0.463	.643
Task* Hand	0.771	0.385	2.002	.045

Note, the memory task was the reference group for task, and the left-hand condition was the reference group for hand. Thus, the effect of task refers to the effect of task within the left-hand condition, and the effect of hand refers to the effect of hand within the memory condition.

This data was then split by task and additional models were conducted. Firstly, the data from children in the memory task was used to compare two models. The first model included hand as a fixed effect and random intercepts by participant. The second model only had a constant and random intercepts by participant. The two models were compared using a likelihood ratio test. The results revealed that there was no effect of hand in the memory task (χ^2 (1) = 0.189, p>.1).

Finally, the data from children in the verb learning task were used to compare two more models. As with the memory comparison, the first model included hand as a fixed effect and random intercepts by participant. The second model only had a constant and random intercepts by participant. The two models were compared using a likelihood ratio test. The results revealed that there was a significant effect of hand in the verb learning task (χ^2 (1) =

6.213, p=.013). Table 8.5 reports the parameters of the model including the main effects of hand (Model 5).

Table 8.5

Fixed effects of Model 5 (fixed effect of hand)

	B	*SE*	*z*	*p*
Intercept	-0.007	0.167	-0.042	.966
Hand	0.619	0.242	2.560	.011

Thus, even when sampling children who found two tasks equally difficult, only the linguistic task benefits from the right-hand response (over the left-hand response). These results cannot be attributed to distraction due to having to use the less dominant (left) hand in a more difficult task.

Discussion

This study investigated whether the hand with which right-handed 3-year-olds use to respond influenced their performance in linguistic (verb learning) and non-linguistic (memory) tasks. Children who were instructed to use their right hand in the verb learning task performed better than children who used their left hand, while no such effect of hand was found in the memory task. Further, in the verb learning task, only children who used their right hand performed better than chance level. Even in the additional analysis that equated the difficulty across the tasks, the key results remained the same: the right-hand advantage was observed in the verb learning task, but not in the memory task. Thus, the right-hand advantage should be attributed to the nature of the tasks (linguistic vs. non-linguistics), but not to the task difficulty. We conclude that responding with the right hand shows an advantage in a linguistic task, but not of a non-linguistic task, for right-handed 3-year-olds.

This study is the first to show that performance in a linguistic task can be influenced by encouraging right-handed children to use their right hand, as opposed to the left-hand, to respond. This finding goes beyond previous correlational findings that right-handed gesturing and vocabulary development are associated (e.g. Cochet et al., 2011; Esseily et al., 2011).

The study builds on research showing that language lateralisation and gesture handedness are associated (e.g. Kimura, 1973a, 1973b). It is also consistent with research showing that encouraging adult participants to use the left hand for gesturing lead to better performance in a metaphor task, which was considered to involve the right hemisphere (Argyriou & Kita, 2013). At a more general level, the current results are consistent with research showing that gesturing can influence linguistic processing in adults and children (e.g. Alibali & Kita, 2010; Mol & Kita, 2012; Frick-Horbury & Guttentag, 1998; Pine et al., 2007) and language learning (e.g. Chapter 4 of the current thesis; Goodrich & Kam, 2009; McGregor et al., 2009).

Possible mechanisms

The mechanisms behind why right-handed pointing showed an advantage over left-handed pointing in performance in the linguistic task are still not clear. We speculate here on two possible accounts (non-mutually exclusive) that differ in the direction of the relationship.

The first account is that using the right hand boosts activation in the left hemisphere, which is where language is typically processed. Research has shown that there is neural overlap between gesture and language processing (e.g. Kimura, 1973a, 1973b; Willems et al., 2007; Skipper et al., 2007). The current study supports the idea that producing right-handed gestures (pointing to respond), increased activation in these areas. This increased activation may make it easier for children to build and access their representation of the new word's referent, resulting in their better performance in the task. Consistent with this idea, people perform better in a word retrieval task when they are tapping their finger than when they do not move their hands, due to bottom-up priming of the key brain areas involved in motor movements and speech production (Ravizza, 2003). However, currently more research is needed to establish how plausible this account may be.

The second account is that as the left hemisphere is typically dominant in the processing and storing of lexical items (e.g. see Indefrey & Cutler, 2004, for a review) the right hand has easier access to these representations. This account is consistent with the finding that split brain patients predominantly used a specific hand for producing gestures with specific functions likely to be lateralised (Lausberg, Davis & Rothenhäuser, 2000). Thus, if children were left lateralised for language, right-handed gestures may have been more accurate due to the direct access to the relevant linguistic representation in the left hemisphere.

It should be noted that we cannot conclude from the current study that right-handed gestures, as compared to other right-handed actions, were crucial to the right-hand over left-hand advantage in the verb learning task. It is possible that any right-handed actions, such as a key press, could show the same influence.

It should also be noted that the current study did not include a baseline condition, so we cannot be sure if right-handed gesturing boosted performance or left-handed pointing was detrimental to performance.

Implications

It should be emphasised that this study investigated gesture handedness and language development, and not manual handedness. The study only included children who were right-handed. Thus, this study does not support the practice of encouraging left-handed children to use their right hand.

The findings of the current study have important practical implications. Pointing is often used in language assessments (e.g. the BPVS). Controlling which hand is used for responses or at least making notes on the spontaneous hand choice may be important for accurate assessment. Furthermore, encouraging right-handed gesturing rather than left-handed gesturing during word learning may facilitate vocabulary development in classrooms or therapeutic settings. Note that on its own encouraging right-handed gesturing may have little effect, but it is possible that it could be integrated into other teaching/ therapeutic techniques to improve word learning. Further, it is still unclear whether encouraging right-handed pointing can facilitate word learning compared to having no gesture handedness manipulation. Further research is now needed to determine how robust and general the effect of gesturing hand on language tasks is.

General Conclusions

This study is the first to experimentally manipulate gesture handedness to investigate its relationship to vocabulary development. The study found that using the right hand to respond showed an advantage in a linguistic task but not in a non-linguistic task. We suggested that this is because the left hemisphere is important in word learning and lexical representation as well as the production of right-hand gestures. The results of this study may have important practical implications although further research is needed to establish this.

CHAPTER 9

GENERAL DISCUSSION

As each chapter contained its own discussion, the general discussion will summarise the keys points, linked between chapters and outline the limitations of the thesis. Implications for future research are then considered.

9.1.

SUMMARY OF MAIN FINDINGS

This thesis investigated the relationship between vocabulary and gesture development in young infants and children. Further, the thesis investigated whether the right hand in particular may be associated with vocabulary development, due to the gesture and language networks overlapping the left hemisphere. I will now give a brief summary of all the empirical chapters:

Chapter 3

This chapter investigated whether 3-year-old children could use iconic gestures to learn the meaning of a novel change-of-state verb, taught over four trials. The study found that although children could match the gestures to the referents in the videos, they were not able to learn the meaning of the novel verbs. The lack of learning, even by the end of the study, suggests that the methodology used was not appropriate to this age range. This was possibly due to the amount of novel features in each of the stimuli, which may have made it difficult for children to focus on the meanings of the verbs.

Chapter 4

This chapter was a follow on from the study in Chapter 3, with the same motivation but an improved methodology. This study taught ambiguous verbs to children that could refer to the manner in the videos, or the change of state. This study found that seeing iconic gestures could influence children's understanding of novel verbs, such that seeing manner gestures made children more likely to believe it was a manner verb than seeing end state gestures or no gestures. This study, therefore, found that iconic gestures could highlight referents within a complex scene, and children could go on to generalise based on these features as a result.

Chapter 6

This chapter investigated the relationship between pointing handedness and vocabulary development in 10- to 12-month-old infants. The results showed a moderate association between receptive vocabulary development and right-handed pointing, such that the two appear to develop together, in the left hemisphere. The direction of this relationship was not clear and possible mechanisms in both directions were discussed. The results also showed a relationship between productive vocabulary and the number of points. This relationship possibly reflects a general ability to communicate referentially.

Chapter 7

This chapter reanalysed data from Chapter 4, in light of the association found in Chapter 6. First, this chapter revealed an association between using the right hand to respond and responding consistently with the gesture seen in training. This association may reflect the neural overlap between gesture production and speech-gesture integration in the left hemisphere. Possible mechanisms for this pattern of results were discussed, although as gesture handedness was not manipulated, the direction remains unclear.

Chapter 8

This chapter manipulated hand choice during a word learning and a memory task. The results showed that, while children who used their left or right hand succeeded in the memory task, only children who used their right hand performed above chance in the verb learning task.

9.2

INFLUENCE OF GESTURE DURING VERB LEARNING

Chapters 3 and 4 addressed the issue of how seeing iconic gestures can help children to map novel verbs to specific aspects of a scene and then generalise the new word to novel contexts on the consistency of this aspect. Previous studies which had investigated the relationship between seeing gestures and mapping words, had not ruled out whether gestures simply make the learning environment more interesting (See Valenzeno, Alibali & Klatzky, 2003) or whether gestures had helped to associate a word with a scene but not focused to the specific referent (Goodrich & Kam, 2009). The current thesis has shown that, while gestures may have these influences, gestures can help children to select a particular referent among competitors, based on their iconic nature.

It is important to understand this relationship, since multi-modal communication is often encouraged. For example, many children with communication impairments are now given access to augmentative and alternative communication (AAC) methods, which can include the use of gesture and signs to support speech (e.g. Wilkinson & Hennig, 2007). In addition, multimodal communication is often encouraged when communicating with typically developing children. For example, some studies encourage signing with typically developing infants to boost language development (e.g. Goodwyn, Acredolo & Brown, 2000). Further, teachers often use gestures in classroom settings to support their verbal communication (e.g. Flevares & Perry, 2001; Alibali & Nathan, 2004). It is, therefore, very important to understand how these signs or gestures are influencing children’s processing of co-occurring speech.

In contrast to common practice with developmental disorders described above, work on gesture therapies with patients with severe aphasia suggests that they may not be very useful (Marshall, Best, Cocks, Cruice, Pring, Bulcock et al., 2012). For example, Marshall and colleagues (2012) compared gesture therapy with verbal therapy in a production context and found that verbal therapies were more effective. Further, other work suggests that speech-gesture integration may be impaired in aphasia (Cocks, Sautin, Kita, Morgan & Zlotowitz, 2009) which would make it difficult for patients to benefit from seeing gestures in the same way as children did in the current thesis.

9.3

RELATIONSHIP BETWEEN GESTURE HANDEDNESS AND LANGUAGE

In Chapter 6 we found an association between receptive vocabulary development in infancy and pointing handedness. Specifically, the results showed that as infants' receptive vocabularies increased, they became more right-handed. This is in line with previous studies (e.g. Locke, Bekken, McMinn-Larson & Wein, 1995; Cochet, Jover & Vauclair, 2011; Esseily, Jacquet & Fagard, 2011; Vauclair & Imbault, 2009). This relationship was then investigated in a post hoc manner (Chapter 7) using data from a verb learning study (Chapter 4), which suggested that there was a relationship between hand choice and response (they used their right hand more often when they responded in line with the experimenter's gestures). This led to the study in Chapter 8, which is the first that we know of to investigate this relationship experimentally. The results of the study in Chapter 8 suggest that there was a right-hand advantage over left hand in a verb learning task, but not in a memory task. The difference between the two tasks was not due to task difficulty.

Taken together, the current thesis provides further evidence that vocabulary development and gestural communication develop together early on in infancy and childhood. Given previous studies on the lateralisation of language (e.g. Knecht, Drager, Deppe, Bobe, Lohmann, Floel et al., 2000) and the right-hand bias found in the current studies, the thesis also provides indirect evidence that this co-development is occurring in the left hemisphere.

The current thesis looked at the relationship between vocabulary development and right-handed gesturing at a younger age than previous research (10-12 months) and also extended the results into older children (36-47 months). By finding these associations across such a broad age range, the current thesis identifies how robust this relationship is.

The study in Chapter 8 is the first to our knowledge to begin to apply this association into an experimental setting. Previous studies have all investigated the relationship in naturalistic and observational settings with correlational analyses. Building on previous work, this new finding is promising as it suggests that it is possible to use this association to boost language abilities. In particular, this study is the first to show the encouraging right-handed pointing may be a useful strategy to use when teaching children new vocabulary. However, the lack of a baseline condition in this study means that we cannot establish how beneficial (if at all) encouraging right-handed gesturing is compared to having no gesture handedness manipulation. Further, it may be more plausible that this would need to be combined with other teaching techniques, rather than used independently. This thesis has therefore extended previous work based on observation by showing how it may be used in applied settings such as education.

9.4

LIMITATIONS OF THE CURRENT THESIS

Experimenter bias

Experimenter bias must be taken into account for all of the studies; especially the ones conducted with 3-year-olds. In all of the studies the experimenter performed the training and testing live, including the production of gestures. Therefore, these will have varied in the way that she performed them. Further, the experimenter was herself aware of the hypothesis and the condition children were in; it was not completed blind.

Although, unconscious experimenter bias has been shown (e.g. Rosenthal & Fode, 1963), there were several reasons the studies were conducted as they were. When working with such young children, we felt it was necessary to do the training in vivo, rather than on a video. Children this age are easily distracted and having a person who can respond to them was critical to keeping them on task. Further, conducting the studies in this way was more ecologically valid, since we were interested in the effects of a speaker's gestures on their abilities, not those of a person on screen. Finally, it was not possible to have a blind confederate run the experiments due to a lack of resources.

The issue of potential for experimenter bias was tackled by the experimenter being aware of the issue. The experiments followed a script for all of the children and the experimenter made sure to practice the experiment thoroughly before testing began. She was also careful not to give any clues to videos through eye gaze and never pointed herself. By simply being aware of experimenter bias and using these techniques, the risk of experimenter bias should have been reduced considerably. It is also clear, by the presence of unexpected results (such as the floor performances in Chapter 3, and the change of state bias seen in children who didn't see gestures in Chapter 4) that experimenter bias was not driving the results.

Lack of video recordings

None of the studies in the current thesis conducted in nurseries with 3-year-old participants were video recorded. This meant there could be no second coder reliability of the data. However, the dependent variable was designed to be as simple as possible (pointing to a screen) and a marking sheet was made, such that it was easy for the experimenter to note responses live, with a low risk of errors. Further, due to the simplicity of the dependent variable it was usually very clear which choice children were making. If at any point, children's response was ambiguous (for example, when they pointed to both videos), they were reminded that they could only select one, and were asked to clarify their response by the experimenter repeating the question to them. It was decided therefore that video recording of the studies, was not necessary.

As well as reliability coding, videos may also be useful for providing raw data of experiments. These may be useful when other researchers wish to replicate a study, since they could see exactly how they were conducted and the contexts in which they were conducted. Video recordings may also be useful in showing how rigorous and truly scientific the discipline of psychology is. Finally, video recording experiments may help to establish best practice, and reduce the possibility of researchers manipulating and even fabricating data sets. There are, however, issues which need to be taken into account when video recording children/ vulnerable individuals. For example, there are ethical issues about who videos are made available to and where they can be stored securely and practical issues such as getting consent from parents to video record their child is very time-consuming and results in a loss of participants. Overall, it may be useful for future developmental studies of this kind to begin to video record studies as standard practice where possible.

Age range

Another issue with the current thesis is the limited age range. Excluding the infant study (10-12 months), all of the studies were conducted with 3-year-olds. It is important, therefore, not to extrapolate the findings to younger or older children, since we do not have evidence to support that. It would be interesting to see how the influences found in the current thesis develop over time, both before 3-years and after.

9.5

FUTURE WORK

The studies from the current thesis have raised many important issues that should be addressed in further research. These issues are across a range of contexts and have important and interesting theoretical and practical applications, in terms of therapy and education.

Chapter 3 can inform future research from a methodological rather a theoretical point of view. This study resulted in floor performance, suggesting that the methods used were not appropriate for these age ranges. The chapter showed that irrelevant novel aspects of video stimuli should be kept as simple as possible when teaching novel words to children (unless the issue of novelty is the question being asked!). The stimuli and paradigm used in Chapter 4 were informed by the studies in Chapter 3, and resulting in performances above floor level.

The results from Chapter 4 have important theoretical and practical implications. This was the first study to show that children can use information contained within gestures to map a referent to a particular feature within a complex scene. From a theoretical point of view, this can inform theories of language development and word learning. As the current study found that manner gestures had a larger impact on word learning than end state gestures, further work should investigate why some iconic gestures have more influential than others. Some possible ideas have been discussed in the chapter. For example, expectancy may play an important role in whether the information in gesture has a large impact (e.g. unexpected information may have a larger impact than expected information). Further, it would be interesting to investigate whether it is the way in which gestures are iconic that is important.

For example, gestures in which the hand becomes the referent may differ in their influence compared to gestures in which children must imagine referents.

It would also be important to understand how robust the influence of gesture on word learning is. It is not clear from the current studies whether iconic gestures can help children to focus on manner or end state at the expense of actors or objects, which are often very salient. It is also important to understand whether gestures can help with other types of verbs other than change of state and manner verbs. For example, it would be interesting to investigate whether highlighting trajectory can help children to understand path verbs. Further, this paradigm could be used to investigate children's use of iconic gestures when learning other word types.

From a practical point of view, it would be useful to understand if children's use of gesture to select the correct referent can also lead to longer lasting and more robust word learning, than simply associating a word with a gesture as seen in previous studies (e.g. Tellier, 2008). In order to do this a study using a delayed post test paradigm would be needed. If it is the case that the process of using gesture to identify a referent can lead to improved word learning, this could be used in education (e.g. for children in a first language or adults in a second language) and to inform therapies for individuals with language impairments.

Finally, it would be interesting and important to investigate the benefit of iconic gestures on word learning processes in language impaired populations. It would be predicted that individuals with some types of impairment (e.g. semantic difficulties) would benefit more than others (e.g. phonological difficulties).

In Chapter 6 we found that even at the very onset, language development and gesture handedness were associated. As handedness was not manipulated in this study, the nature of this relationship remains unclear (although Chapter 8 did address this issue with older children). In Chapter 6, two possible accounts are mentioned, which both suggest that this association is the result of social interactions with adults. One explanation suggests that using the right hand, boosts activation in the language areas of the brain, making word learning more efficient. Conversely, it may be that when caregivers ask their child where referents are (e.g. '*where's the doggie?*'), the language processing boosts activation in the left hemisphere such that the right hand is more likely to produce the pointing response. Children who have larger vocabularies experience more of these interactions resulting in a right-hand bias, even when the gesture is not a response to a direct question. Both of these accounts can be testing empirically.

To test the first explanation (right-handed gesturing leads to more efficient word learning), infants could be shown unfamiliar objects and given a novel label for these objects when they point to them. Pointing handedness could be manipulated by placing toys on the far sides of the midline. After training, infants' word learning could be tested using a preferential looking paradigm with two objects (one target and one distracter) and hear the new label. If this account is true then infants' who were encouraged to use their right hand to point would show improved word learning that children who were encouraged to use their left hand to point.

To test the second hypothesis (responding to verbal questions leads to an increase in right-handedness), infants could be shown attractive toys. On some trials infants could be asked to point to a particular known toy ('*where's the car?*') and on other trials infants could point to whichever toy they preferred. If this account is true then asking children a question should result in a stronger right-hand bias than free pointing. This could be investigated with children with a range of vocabulary sizes.

Another important area of research that this study motivates has a more practical and applied basis. It is important to understand how robust and reliable the association between very early gesture handedness and language development is. Therefore, it would be interesting and useful to replicate this study but follow the infants longitudinally to investigate their later language development. Infants in the current study's age range (10-12 months) typically do not produce very many words and so detecting language impairments this young is a challenge. If gesture handedness can be used as an indicator for language development, then it could potentially be used as a marker for language impairments. It would also be a useful marker for multilingual children, whose verbal development is delayed by the acquisition of multiple languages compared to unilingual children. This typical delay makes it difficult to detect language impairments in multilingual children, but gesture may be a potential marker for this population too. However, it is important to note that the sample size in the current study was small and far more research would be needed before any attempt at practical applications is made. Further, it is very unlikely that gesture handedness alone could detect language impairments, and additional information about the child's development would also be needed.

The study in Chapter 8 shows promise for a new and exciting area of research. Manipulating gesture handedness influenced children's performance in a word learning task. Whilst far more research is required on this topic, this could have future implication in terms therapy and teaching strategies especially if combined with other techniques.

First, it would be useful to see how reliable and robust this effect is. To do this, a simple replication study could be conducted. It is also important to see if the effect can be generalised across various linguistics tasks and across ages.

It would also be important to understand whether different types of words or linguistic structures benefit more from this type of activational boost in the left hemisphere. It may be useful to demonstrate double dissociations between left and right gesture handedness and improved performance in right and left-hemisphere dominant tasks. For example, while word learning may be improved by right-handed gesturing, emotional processing of tone may be improved by left-handed gesturing, since this is thought be right lateralised (e.g. Buchanan, Lutz, Mirzazade, Specht, Shah, Zilles et al., 2000). Similarly, when speaking in metaphors (which are processed in the right hemisphere), it may be harmful to encourage right-handed gesturing. Indeed, Argyriou and Kita (2013) found that when adult participants were told to use their right hand, their speech contained less metaphorical content than when they used their left hand.

Further, the current thesis only investigated pointing gestures. It would be interesting to manipulate handedness while participants used iconic gestures. It may be that information contained in iconic gestures while learning words becomes more integrated into the representation for the new word, when the right hand is used compared to the left. The current thesis used pointing gestures after a pilot study revealed that getting children to produce specific iconic gestures with their left and right hands was too difficult. Perhaps future research could investigate this effect with older children, or allow children to produce flexible iconic gestures, rather than specific ones.

Finally, the current study assumed that the majority of participants were developing language lateralised to the left hemisphere. It would be useful for future research to take a measurement of language lateralisation for each participant. For example, if children were developing language lateralised to the right hemisphere the opposite effects may be predicted, such that left-handed gesturing may improve linguistic performance.

9.6

GENERAL CONCLUSIONS

This thesis investigated the relationships between gesture and vocabulary during infancy and childhood. There are three key findings which are new to the literature and so have advanced our understanding of the complex association between gesture and language development.

First, in Part I of the thesis, we found that children can use iconic gestures to select a referent for a novel verb when the meaning of that verb is unclear from context alone (Chapter 4). Although previous research has investigated the influence of gestures during word learning, this study is the first to our knowledge to show that gestures can help children zero in on particular features, rather than simply making the interaction more engaging.

Secondly, in Part II, we found evidence suggesting that receptive vocabulary and imperative pointing co-develop in the left hemisphere at the onset of referential communication (Chapter 6). Although the relationship between right-handed gesturing and vocabulary development has been found before, this study found it in younger infants. The study also ruled out possible alternative accounts for previous findings, such as the relationship is mediated by age, or vocalisations. Further, the study found that language comprehension, rather than production, may play a key role in associating gestures to the left hemisphere in infancy.

Finally, we found a right hand over left hand advantage in a linguistic task (Chapter 8). This was not due to dexterity as a control memory task did not show the same influence of handedness. This is the first study of its kind to experimentally manipulate handedness in this way to observe the effects on cognition. Although further research is now required to assess the nature of the observed effect, the results of this study may have broad implications, both theoretical (e.g. how language and gesture interact at the neuronal level) and practical (e.g. strategies for teaching and therapy).

This thesis has advanced our understanding of the relationship between vocabulary and gesture development in typically developing children. Early childhood vocabulary is very important, and is known to predict several aspects of later life (e.g. Law, Rush, Schoon & Parsons, 2009). It is, therefore, crucial that we understand how it can be developed. It is now important to continue to investigate the issues raised by the current thesis. In particular it would be useful to know if these effects transfer to children who are having difficulties in learning a language, in order to guide therapy or teaching strategies for these children.

REFERENCES

Akhtar, N., Carpenter, M., & Tomasello, M. (1996). The role of discourse novelty in early word learning. *Child Development, 67,* 635-645. doi:10.1111/j.1467-8624.1996.tb01756.x

Alibali, M. W., & Kita, S. (2010). Gesture highlights perceptually present information for speakers. *Gesture, 10,* 3-28. doi:10.1075/gest.10.1.02ali

Alibali, M. W., & Nathan, M. J. (2004). The role of gesture in instructional communication: Evidence form an early algebra lesson. *In W. A. Sandoval, N. Enyedy, A.S. Nixon, & F. Herrera (Eds). Proceedings of the 6th International conference of the Learning Sciences, held at the University of California, Los Angeles, Santa Monica, USA, 22-26th June 2004* (pp. 36-43). Mahway, NJ : Lawrence Erlbaum.

Argyriou, P. & Kita, S. (2013). The Effect of Left-Hand Gestures on Metaphor Explanation. *In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), Proceedings of the 35th Annual Conference of the Cognitive Science Society, held in Berlin, Germany, 31st July-3rd August* (pp. 1762-1767). Austin, TX: Cognitive Science Society

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development, 62,* 875-890. doi:10.2307/1131140

Baldwin, D. A. (1993). Infants' ability to consult the speaker for clues to word reference, *Journal of Child Language, 20,* 395-418. doi:10.1017/S0305000900008345

Baldwin, D. A., Markman, E. M., Bill, B., Desjardins, N., Irwin, J. M., & Tidball, G. (1996). Infants' reliance on a social criterion for establishing word-object relations. *Child Development, 67,* 3135-3153. doi:10.1111/j.1467-8624.1996.tb01906.x

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255-278. doi:10.1016/j.jml.2012.11.001

Bates, D. M., Maechler, M., & Bolker, B. (2013). lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-2.

Bates, E. (1976). *Language and context: The acquisition of pragmatics.* New York: Academic Press.

Bates, E., Camaioni, L., & Volterra, V. (1975). The acquisition of performatives prior to speech. *Merrill-Palmer Quarterly, Journal of Developmental Psychology,* 21(3), 205-226. (Reprinted in E. Ochs & B. Schieffelin, Eds., *Developmental pragmatics.* New York: Academic Press, 1979, 111-128).

Beaton, A. A. (1997). The relation of planun temporale asymmetry and morphology of the corpus callosum to handedness, gender, and dyslexia: A review of the evidence. *Brain and Language, 60,* 255-322. doi:10.1006/brln.1997.1825

Beattie, G., & Coughlan, J. (1999). An experimental investigation of the role of iconic gestures in lexical access using the tip-of-the-tongue phenomenon. *British Journal of Psychology, 90,* 35-56. doi:10.1348/000712699161251

Beattie, G., & Shovelton, H. (2000). Iconic hand gestures and the predictability of words in context in spontaneous speech. *British Journal of Psychology, 91,* 473-491. doi:10.1348/000712600161943

Behrend, D. A. (1990). The development of verb concepts- Children’s use of verbs to label familiar and novel events. *Child Development, 61,* 681-696. doi:10.1111/j.1467-8624.1990.tb02811.x

Bernardis, P., & Gentilucci, M. (2006). Speech and gesture share the same communication system. *Neuropsychologia, 44,* 178-190. doi:10.1016/j.neuropsychologia.2005.05.007

Bickerton, W. L., Riddoch, M. J., Samson, D., Balani, A. B., Mistry, B., & Humphreys, G. W. (2012). Systematic assessment of apraxia and functional predictions from the Birmingham Cognitive Screen. *Journal of Neurology, Neurosurgery and Psychiatry, 83,* 513-521. doi:10.1136/jnnp-2011-300968

Binder, J.R., Frost, J.A., Hammeke, T.A., Cox, R.W., Rao, S.M., & Prieto, T. (1997). Human brain language areas identified by functional magnetic resonance imaging. *Journal of Neuroscience, 17,* 353-362.

Bishop, D. V. M. (2005). Handedness and specific language impairment: a study of 6-year-old twins. *Developmental Psychobiology, 46,* 362-369. doi:10.1002/dev.20062

Blake, J., O'Rourke, P., & Borzellino, G. (1994). Form and function in the development of pointing and reaching gestures. *Infant Behavior and Development, 17,* 195-203. doi:10.1016/0163-6383(94)90055-8

Bonda, E., Petrides, M., Ostry, D., & Evans, A. (1996). Specific involvement of human parietal systems and the amygdala in the perception of biological motion. *Journal of Neuroscience, 16,* 3737-3744.

Bonvillian, J. D., Richards, H. C., & Dooley, T. T. (1997). Early sign language acquisition and the development of hand preference in young children. *Brain and Language, 58,* 1-22. doi:10.1006/brln.1997.1754

Booth, A. E., McGregor, K. K. & Rohlfing, K. (2008). Socio-pragmatics and attention: Contributions to gesturally guided word learning in toddlers. *Language Learning and Development, 4,* 179–202. doi:10.1080/15475440802143091

Bornstein, M. H., Cote, L. R., Maital, S., Painter, K., Park, S. Y., Pascual, L., Pecheux, M. G., Reul, J., Venuti, P., & Vyt, A. (2004). Cross-linguistic analysis of vocabulary in young children: Spanish, Dutch, French, Hebrew, Italian, Korean and American English. *Child Development, 75,* 1115-1139. doi:10.1111/j.1467-8624.2004.00729.x

Borod, J. C., Haywood, C. S., & Koff, E. (1997). Neuropsychological aspects of facial asymmetry during emotional expression: A review of the normal adult literature. *Neuropsychology Review, 7,* 41-60. doi:10.1007/BF02876972

Boyatzis, C. J., & Watson, M. W. (1993). Preschool children's symbolic representation of objects through gestures. *Child Development, 64,* 729-735. doi:10.1111/j.1467-8624.1993.tb02939.x

Broaders, S. C., Goldin-Meadow, S. (2010). Truth is at hand: How gesture adds information during investigative interviews. *Psychological Science, 21,* 623-628. doi:10.1177/0956797610366082

Broca, P. (1861). Remaquessur le siege la faculte du langagearticule; suiviesd'une observation d'aphemie. Bull. Soc. Anat. Paris 6, 330–357.

Buchanan, T. W., Lutz, K., Mirzazade, S., Specht, K., Shah, N. J., Zilles, K., & Jancke, L. (2000). Recognition of emotional prosody and verbal components of spoken language: an fMRI study. *Cognitive Brain Research, 9,* 227-238. doi: 10.1016/S0926-6410(99)00060-9

Burnham, K. P., & Anderson, D. A. (2002). *Model Selection and Multimodel Inference. A Practical Information-Theoretic Approach (2nd Ed).* Springer-Verlag New York.

Butterworth, G., & Morissette, P. (1996). Onset of pointing and the acquisition of language in infancy. *Journal of Reproductive and Infant Psychology, 14,* 219-231. doi:10.1080/02646839608404519

Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: an empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12,* 1-47. doi:10.1162/08989290051137585

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development*, *15,* 17-29.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, *63*. V-143. doi:10.2307/1166214

Childers, J. B. (2011). Attention to multiple events helps two-and-a-half-year-olds extend new verbs. *First Language*, *31,* 3-22. doi:10.1177/0142723710361825

Cicone, M., Wapner, W., Foldi, N., Zurif, E., & Gardner, H. (1979). Relation between gesture and language in aphasic communication. *Brain and Language, 8,* 324-349. doi:10.1016/0093-934X(79)90060-9

Cincotta, M., & Ziemann, U. (2008). Neurophysiology of unimanual motor control and mirror movements. *Clinical Neurophysiology, 119,* 744-762. doi:10.1016/j.clinph.2007.11.047

Clark, E. V. (1987). *The principle of contrast: a constraint on language acquisition.* In B. MacWinney (Ed), the 20th Annual Carnegie Symposium on Cognition. Laurence Erlbaum Associates Inc: Hillsdale, New Jersey.

Clark, E. V., & Estigarribia, B. (2011). Using speech and gesture to introduce new objects to young children. *Gesture*, *11*, 1-23. doi:10.1075/gest.11.1.01cla

Clopper, C. G. (2013). Modeling multi-level factors using linear mixed effects. *Proceedings of Meetings of Acoustics, 19.* held in Montreal, Canada, 2-7 June 2013. doi:10.1121/1.4799729

Cochet, H., Jover, M., & Vauclair, J. (2011). Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period. *Journal of Experimental Child Psychology, 110,* 393-407. doi:10.1016/j.jecp.2011.04.009

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,* 431-441. doi:10.1016/j.infbeh.2010.04.009

Cocks, N., Sautin, L., Kita, S., Morgan, G & Zlotowitz, S. (2009). Gesture and speech integration: an exploratory study of a man with aphasia. *International Journal of Language and Communication Disorders, 44,* 795-804. doi:10.1080/13682820802256965

Colonnesi, C., Stams, G. J. J. M., Koster, I., & Noom, M. J. (2010). The relation between pointing and language development: a meta-analysis. *Developmental Review, 30,* 352-366. doi:10.1016/j.dr.2010.10.001

Corballis, M. C. (2003). From mouth to hand: gesture, speech, and the evolution of right-handedness. *Behavioral and Brain Sciences, 26,* 199- 260. doi:10.1017/S0140525X03000062

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences, 13,* 148-153. doi:10.1016/j.tics.2009.01.005

Cubelli, R., Marchetti, C., Boscolo, C., & Della Sala, S. (2000). Cognition in action: Testing a model of limb apraxia. *Brain and Cognition, 44,* 144-165. doi:10.1006/brcg.2000.1226

Dalby, J. T., Gibson, D., Grossi, V., & Schneider, R. D. (1980). Lateralized hand gesture during speech. *Journal of Motor Behavior, 12,* 292-297.

de Guiber, C., Maumet, C., Jannin, P., Ferre, J. C., Treguier, C., Barillot, C., Le Rumeur, E., Allaire, C., & Biraben, A. (2011). Abnormal functional lateralization and activity of language brain areas in typical specific language impairment (developmental dysphasia). *Brain, 134,* 3044-3058. doi:10.1093/brain/awr141

Decety, J., Grezes, J., Costes, N., Perani, D., Jeannerod, M., Procyk, E., Grassi, F., & Fazio, F. (1997). Brain activity during observation of actions- Influence of action content and subject's strategy. *Brain, 120,* 1763-1777. doi:10.1093/brain/120.10.1763

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *Science, 298,* 2013-2015. doi:10.1126/science.1077066

DeLoache, J. S., & Demendoza, O. A. P. (1987). Joint picturebook interactions of mothers and 1-year-old children. *British Journal of Developmental Psychology, 5,* 111-123. doi:10.1111/j.2044-835X.1987.tb01047.x

Eglinton, E., & Annett, M. (1994). Handedness and dyslexia- a meta-analysis. *Perceptual and Motor Skills, 79,* 1611-1616. doi:10.2466/pms.1994.79.3f.1611

Esseily, R., Jacquet, A. Y., & Fagard, J. (2011). Handedness for grasping objects and pointing and the development of language in 14-month-old infants. *Laterality, 16,* 565-585. doi:10.1080/1357650X.2010.499911

Esslen, M., Pascual-Marqui, R. D., Hell, D., Kochi, K., & Lehmann, D. (2004). Brain areas and time course of emotional processing. *Neuroimage, 21,* 1189-1203. doi:10.1016/j.neuroimage.2003.10.001

Estes, K. G., Edwards, J., & Saffran, J. R. (2011). Phonotactic constraints on infant word learning. *Infancy, 16,* 180-197. doi:10.1111/j.1532-7078.2010.00046.x

Fagard, J., & Lockman, J. J. (2005). The effect of task constraints on infants' (bi)manual strategy for grasping and exploring objects. *Infant Behavior and Development, 28,* 305-315. doi:10.1016/j.infbeh.2005.05.005

Feyereisen, P. (1983). Manual activity during speaking in aphasic subjects. *International Journal of Psychology, 18,* 545-556. doi:10.1080/00207598308247500

Feyereisen, P. (2006). Further investigation of the mnemonic effect of gestures: Their meaning matters. *European Journal of Cognitive Psychology, 18,* 185-205. doi:10.1080/09541440540000158

Flevares, L. M., & Perry, M. (2001). How many do you see? The use of non-spoken representations in first-grade mathematics lessons. *Journal of Educational Psychology, 93,* 330-345. doi:10.1037//0022-0663.93.2.330

Forbes, J. N., & Farrar, M. J. (1993). Children's initial assumptions about the meaning of novel motion verbs- biased and conservative. *Cognitive Development*, *8*, 273-290. doi:10.1016/S0885-2014(93)80002-B

Forbes, J. N., & Farrar, M. J. (1995). Learning to represent word meaning- What initial training events reveal about children's developing action verb concepts. *Cognitive Development, 10,* 1-20. doi:10.1016/0885-2014(95)90016-0

Foundas, A. L., Macauley, B. L., Raymer, A. M., Maher, L. M., Heilman, K.M., & Rothi, L. J. G. (1995). Gesture laterality in aphasic and apraxic stroke patients. *Brain and cognition, 29,* 204-213. doi:10.1006/brcg.1995.1277

Frick-Horbury, D., & Guttentag, R. E. (1998). The effects of restricting hand gesture production on lexical retrieval and free recall. *American Journal of Psychology, 11,* 43-62. doi:10.2307/1423536

Frost, J. A., Binder, J. R., Springer, J. A., Hammeke, T. A., Bellgowan, P. S. F., Rao, S. M., & Cox, R. W. (1999). Language processing is strongly left lateralized in both sexes-evidence from functional MRI. *Brain, 122,* 199-208. doi:10.1093/brain/122.2.199

Fusaro, M., & Harris, P. L. (2008). Children assess informant reliability using bystanders' non-verbal cues. *Developmental Science, 11,* 771-777. doi:10.1111/j.1467-7687.2008.00728.x

Gallagher, H. L., & Frith, C. D. (2004). Dissociable neural pathways for the perception and recognition of expressive and instrumental gestures. *Neuropsychologia, 42,* 1725-1736. doi:10.1016/j.neuropsychologia.2004.05.006

Gelman, S. A., & Coley, J. D. (1990). The importance of knowing a dodo is a bird - categories and inferences in 2-year-old children. *Developmental Psychology, 26,* 796-804. doi:10.1037/0012-1649.26.5.796

Gentilucci, M., & Volta, R. D. (2008). Spoken language and arm gestures are controlled by the same motor control system. *Quarterly Journal of Experimental Psychology, 61,* 944-957. doi:10.1080/17470210701625683

Gentner, D. (1978). On relational meaning - acquisition of verb meaning. *Child Development, 49,* 988-998. doi:10.1111/j.1467-8624.1978.tb04067.x

Gentner, D. (1982). Why nouns are learned before verbs: Linguistic relativity versus natural partitioning. In S. Kuczaj II (Ed.), *Language development: Vol 2: Language, though, and culture (pp.301-334).* Hillsdale, NJ: Lawrence Erlbaum.

Gertner, Y., Fisher, C., & Eisengart, J. (2006). Learning words and rules: Abstract knowledge of word order in early sentence comprehension. *Psychological Science, 17,* 684-691. doi:10.1111/j.1467-9280.2006.01767.x

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist, 52,* 45-56.

Geschwind, N. (1970). Organization of language and brain. *Science, 170,* 940-944. doi:10.1126/science.170.3961.940

Gilbert, A. N., & Wysocki, C. J. (1992). Hand preference and age in the United-States. *Neuropsychologia, 30,* 601-608. doi:10.1016/0028-3932(92)90065-T

Gleitman, L. (1990). The structural sources of verb meanings. *Language Acquisition, 1,* 3-55. doi:10.1207/s15327817la0101_2

Gleitman, L. R., & Gleitman, H. (1992). A picture is worth a thousand words- but that's the problem: The role of syntax in vocabulary acquisition. *Current Directions in Psychological Science, 1,* 31-35. doi:10.1111/1467-8721.ep10767853

Glenberg, A. M., & Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex, 48,* 905-922. doi:10.1016/j.cortex.2011.04.010

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9,* 558-565. doi:10.3758/BF03196313

Goldin-Meadow, S. (2000). Beyond words: The importance of gesture to researchers and learners. *Child Development, 71,* 231-239. doi:10.1111/1467-8624.00138

Goldin-Meadow, S., Seligman, M. E. P., & Gelman, R. (1976). Language in the two-year old. *Cognition, 4,* 189-202. doi:10.1016/0010-0277(76)90004-4

Golinkoff, R. M., Chung, H. L., Hirsh-Pasek, K., Liu, J., Bertenthal, B. I., Brand, R., Maguire, M. J., & Hennon, E. (2002). Young children can extend motion verbs to point-light displays. *Developmental Psychology, 38,* 604-614. doi:10.1037//0012-1649.38.4.604

Golinkoff, R. M., Hirsh-Pasek, K., Mervis, C. B., Frawley, W., & Parillo, M. (1995b). *Lexical principles can be extended to the acquisition of verbs*. In M. Tomasello & W. Merriman (Eds.), Beyond names for things: Young children's acquisition of verbs (pp. 185-222). Hillsdale, NJ: Lawrence Erlbaum Associates.

Golinkoff, R. M., Jacquet, R. C., Hirsh-Pasek, K., & Nandakumar, R. (1996). Lexical Principles May Underlie the Learning of Verbs. *Child Development, 67,* 3101-3119. doi:10.1111/j.1467-8624.1996.tb01905.x

Golinkoff, R. M., Mervis, C. B., & Hirsh-Pasek, K. (1994). Early object labels- The case for a developmental lexical principles framework. *Journal of Child Language, 21,* 125-155. doi:10.1017/S0305000900008692

Golinkoff, R. M., Shuff-Bailey, M., Olguin, R., & Ruan, W. (1995a). Young children extend novel words at the basic level: Evidence for the principle of the categorical scope. *Developmental Psychology, 31,* 494-507. doi:10.1037/0012-1649.31.3.494

Gómez, R. L. (2002). Variability and detection of invariant structure. *Psychological Science, 13,* 431-436. doi:10.1111/1467-9280.00476

Goodrich, W., & Kam, C. L. H. (2009). Co-speech gesture as input in verb learning. *Developmental Science, 12,* 81-87. doi:10.1111/j.1467-7687.2008.00735.x

Goodwyn, S. W., Acredolo, L. P., & Brown, C. A. (2000). Impact of symbolic gesturing on early language development. Journal of Nonverbal Behavior, 24, 81-103. doi:10.1023/A:1006653828895

Graham, S. A., Nilsen, E. S., Collins, S., & Olineck, K. (2010). The role of gaze direction and mutual exclusivity in guiding 24-month-olds' word mappings. *British Journal of Developmental Psychology, 28,* 449-465. doi:10.1348/026151009X424565

Graham, S. A., & Poulin-Dubois, D. (1999). Infants' reliance on shape to generalize novel labels to animate and inanimate objects. *Journal of Child Language, 26,* 295-320. doi:10.1017/S0305000999003815

Grassmann, S., & Tomasello, M. (2010). Young children follow pointing over words in interpreting acts of reference. *Developmental Science, 13,* 252-263. doi:10.1111/j.1467-7687.2009.00871.x

Graves, R., Goodglass, H., & Landis, T. (1982). Mouth asymmetry during spontaneous speech. *Neuropsychologia, 20*, 371-381. doi:10.1016/0028-3932(82)90037-9

Gredebäck, G., Melinder, A., Daum, M. (2010) The Development and Neural Basis of Pointing Comprehension. *Social Neuroscience, 5,* 441-450. doi:10.1080/17470910903523327

Gropen, J., Pinker, S., Hollander, M., & Goldberg, R. (1991). Syntax and semantics in the acquisition of locative verbs. *Journal of Child Language, 18,* 115-151. doi:10.1017/S0305000900013325

Haaland, K. Y., Harrington, D. L., & Knight, R. T. (2000). Neural representation of skilled movement. *Brain, 123,* 2306-2313. doi:10.1093/brain/123.11.2306

Hadar, U., Wenkert-Olenik, D., Krauss, R., & Soroker, N. (1998). Gesture and the processing of speech: Neuropsychological evidence. *Brain and Language, 62,* 107-126. doi:10.1006/brln.1997.1890

Hamilton, A., Plunkett, K., & Schafer, G. (2000). Infant vocabulary development assessed with a British Communicative Development Inventory: Lower scores in the UK than the USA. *Journal of Child Language, 27,* 689-705. doi:10.1017/S0305000900004414

Hansen, M. B., & Markman, E. M. (2009). Children's use of mutual exclusivity to learn labels for parts of objects. *Developmental Psychology, 45,* 592-596. doi:10.1037/a0014838

Hatta, H., & Dimond, S. J. (1984). Differences in face touching by Japanese and British people. *Neurospsychologia, 22,* 531-534. Doi:10.1016/0028-3932(84)90050-2

Heibeck, T. H., & Markman, E. M. (1987). Word learning in children- an examination of fast mapping. *Child Development, 58,* 1021-1034. doi:10.1111/j.1467-8624.1987.tb01438.x

Hepper, P. G., Wells, D. L., & Lynch, C. (2005). Prenatal thumb sucking is related to postnatal handedness. *Neuropsychologia, 43,* 313-315. doi:10.1016/j.neuropsychologia.2004.08.009

Herold, D. S., Nygaard, L. C., Chicos, K. A., & Namy, L. L. (2011). The developing role of prosody in novel word interpretation. *Journal of Experimental Child Psychology, 108,* 229-241. doi:10.1016/j.jecp.2010.09.005

Holle, H., & Gunter, T. C. (2007). The role of iconic gestures in speech disambiguation: ERP evidence. *Journal of Cognitive Neuroscience, 19,* 1175-1192. doi:10.1162/jocn.2007.19.7.1175

Holle, H., Obleser, J., Rueschemeyer, S. A., & Gunter, T. C. (2010). Integration of iconic gestures and speech in left superior temporal areas boosts speech comprehension under adverse listening conditions. *Neuroimage, 49,* 875-884. doi:10.1016/j.neuroimage.2009.08.058

Hollich, G. J., Hirsh-Pasek, K., Golinkoff, R. M., Brand, R. J., Brown, E., Chung, H. L., Hennon, E., & Rocroi, C. (2000). Breaking the language barrier: An emergentist coalition model for the origins of word learning. *Monographs of the Society for Research in Child Development, 65*, 5–123.

Holowka, S., & Petitto, L. A. (2002). Left hemisphere cerebral specialization for babies while babbling. *Science, 297,* 1515-1515. doi:10.1126/science.1074941

Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science, 9,* 131-134. doi:10.1111/1467-9280.00024

Hopkins, W. D., & Cantero, M. (2003). From hand to mouth in the evolution of language: the influence of vocal behavior on lateralized hand use in manual gestures by chimpanzees (*Pan troglodytes*). *Developmental Science, 6,* 55-61. doi:10.1111/1467-7687.00254

Hostetter, A. B. (2011). When Do Gestures Communicate? A Meta-Analysis. *Psychological Bulletin, 137*, 297-315. doi:10.1037/a0022128

Imai, M., Haryu, E., & Okada, H. (2005). Mapping novel nouns and verbs onto dynamic action events: Are verb meanings easier to learn than noun meanings for Japanese children? *Child Development, 76,* 340-355. doi:10.1111/j.1467-8624.2005.00849_a.x

Imai, M., Kita, S., Nagumo, M., & Okada, H. (2008). Sound symbolism facilitates early verb learning. *Cognition, 109,* 54-65. doi:10.1016/j.cognition.2008.07.015

Indefrey, P., & Cutler, A. (2004). Prelexical and lexical processing in listening. *In M. S. Gazzangia (Eds). Cognitive Neurosciences III, Third Edition*, 759-774.

Iverson, J. M., & Fagan, M. K. (2004). Infant vocal-motor coordination: precursor to the gesture-speech system? *Child Development, 75,* 1053-1066. doi:10.1111/j.1467-8624.2004.00725.x

Iverson, J. M., & Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological Sciences, 16,* 367-371. doi:10.1111/j.0956-7976.2005.01542.x

Jacquet, A. Y., Esseily, R., Rider, D., & Fagard, J. (2012). Handedness for grasping objects and declarative pointing: A longitudinal study. *Developmental Psychobiology, 54,* 36-46. doi:10.1002/dev.20572

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*(4), 434-446. doi:10.1016/j.jml.2007.11.007

Jaswal, V. K. (2010). Explaining the disambiguation effect: Don't exclude mutual exclusivity. *Journal of Child Language, 37,* 95-113. doi:10.1017/S0305000909009519

Jaswal, V. K., & Hansen, M. B. (2006). Learning words: children disregard some pragmatic information that conflicts with mutual exclusivity. *Developmental Science, 9,* 158-165. doi:10.1111/j.1467-7687.2006.00475.x

Kantartzis, K., Imai, M., & Kita, S. (2011). Japanese sound-symbolism facilitates word learning in English-speaking children. *Cognitive Science, 35,* 575-586. doi:10.1111/j.1551-6709.2010.01169.x

Kean, M. L. (1977). Linguistic interpretation of aphasic syndromes- agrammatism in Broca's aphasia, an example. *Cognition, 5,* 9-46. doi:10.1016/0010-0277(77)90015-4

Kelly, S. D. (2001). Broadening the units of analysis in communication: speech and nonverbal behaviours in pragmatic comprehension. *Journal of Child Development, 28,* 325-349.

Kelly, S. D., Barr, D. J., Church, R. B., & Lynch, K. (1999). Offering a hand to pragmatic understanding: The role of speech and gesture in comprehension and memory. *Journal of Memory and Language, 40,* 577-592. doi:10.1006/jmla.1999.2634

Kelly, S. D., & Church, R. B. (1998). A comparison between children's and adults' ability to detect conceptual information conveyed through representational gestures. *Child Development, 69,* 85-93. doi:10.1111/j.1467-8624.1998.tb06135.x

Kelly, S. D., Creigh, P., & Bartolotti, J. (2010a). Integrating speech and iconic gestures in a stroop-like task: Evidence for automatic processing. *Journal of Cognitive Neuroscience, 22,* 683-694. doi:10.1162/jocn.2009.21254

Kelly, S. D., Kravitz, C., & Hopkins, M. (2004). Neural correlates of bimodal speech and gesture comprehension. *Brain and Language, 89,* 243-260. doi:10.1016/S0093-934X(03)00335-3

Kelly, S. D., McDevitt, T., & Esch, M. (2009). Brief training with co-speech gesture lends a hand to word learning in a foreign language. *Language and Cognitive Processes, 24,* 313-334. doi:10.1080/01690960802365567

Kelly, S. D., Özyürek, A., & Maris, E. (2010b). Two sides of the same coin: Speech and gesture mutually interact to enhance comprehension. *Psychological Science, 21,* 260-267. doi:10.1177/0956797609357327

Kemmerer, D., Chandrasekaran, B., & Tranel, D. (2007). A case of impaired verbalization but preserved gesticulation of motion events. *Cognitive Neuropsychology, 24,* 70-114. doi:10.1080/02643290600926667

Kendon, A. (1988). How gestures can become like words. In Potyatos, F. (ed), *Crosscultural perspectives in nonverbal communication, p 131-141*. Toronto, Canada: Hogrefe.

Kendon, A. (1994). Do gestures communicate: a review. *Research on Language and Social Interaction, 27*, 175-200. doi:10.1207/s15327973rlsi2703_2

Kersten, A. W., & Smith, L. B. (2002). Attention to novel objects during verb learning. *Child Development, 73,* 93-109. doi:10.1111/1467-8624.00394

Kidd, E., & Holler, J. (2009). Children's use of gesture to resolve lexical ambiguity. *Developmental Science, 12,* 903-913. doi:10.1111/j.1467-7687.2009.00830.x

Kim, S. G., Ashe, J., Hendrich, K., Ellermann, J. M., Merkle, H., Ugurbil, K., & Georgopoulos, A. P. (1993). Functional magnetic-resonance-imaging of motor cortex-Hemispheric-asymmetry and handedness. *Science, 261,* 615-617. doi:10.1126/science.8342027

Kimbara, I. (2008). Gesture form convergence in joint description. *Journal of Nonverbal Behavior*, 32, 123-131. doi:10.1007/s10919-007-0044-4

Kimura, D. (1973a). Manual activity during speaking. 1. Right-handers. *Neuropsychologia, 11,* 45-50. doi:10.1016/0028-3932(73)90063-8

Kimura, D. (1973b). Manual activity during speaking. 2. Left-handers. *Neuropsychologia, 11,* 51-55. doi:10.1016/0028-3932(73)90064-X

Kishimoto, T., Shizawa, Y., Yasuda, J., Hinobayashi, T., & Minami, T. (2007). Do pointing gestures by infants provoke comments from adults? *Infant Behavior and Development, 30,* 562-567. doi:10.1016/j.infbeh.2007.04.001

Kita, S. (2000). *How representational gestures help speaking*. In D. McNeill (Ed.), Language and Gesture. Cambridge: Cambridge University Press.

Kita, S., de Condappa, O., & Mohr, C. (2007). Metaphor explanation attenuates the right-hand preference for depictive co-speech gestures that imitate actions. *Brain and Language, 101,* 185-197. doi:10.1016/j.bandl.2006.11.006

Kita, S., & Lausberg, H. (2008). Generation of co-speech gestures based on spatial imagery from the right-hemisphere: Evidence from split-brain patients. *Cortex, 44,* 131-139. doi:10.1016/j.cortex.2006.04.001

Kita, S., & Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal?: Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and Language, 48,* 16-32. doi.10.1016/S0749-596X(02)00505-3

Kita, S., Özyürek, A., Allen, S., & Ishizuka, T. (2010). Early links between iconic gestures and sound symbolic words: evidence for multimodal protolanguage. *In A. D. M. Smith, M. Schouwstra, B. De Boer, B, & K. Smith (Eds.), The Evolution of Language: Proceedings of the 8th International Conference on the Evolution of Language (EVOLANG 8) held in Utrecht, Netherlands, 14-17 April 2010* (pp. 429-430). Singapore: World Scientific Press. doi:10.1142/9789814295222_0077

Knecht, S., Drager, B., Deppe, M., Bobe, L., Lohmann, H., Floel, A., Ringelstein, E. B., & Henningsen, H. (2000). Handedness and hemispheric language dominance in healthy humans. *Brain, 123,* 2512-2518. doi:10.1093/brain/123.12.2512

Knecht, S., Drager, B., Floel, A., Lohmann, H., Breitenstein, C., Deppe, M., Henningsen, H., Ringelstein, E.B. (2001). Behavioural relevance of atypical language lateralization in healthy subjects. *Brain, 124,* 1657-1665. .doi:10.1093/brain/124.8.1657

Kobayashi, H. (1997). The role of actions in making inferences about the shape and material of solid objects among Japanese 2 year-old children. *Cognition, 63,* 251-269. doi:10.1016/S0010-0277(97)00007-3

Kobayashi, H. (1998). How 2-year-old children learn novel part names of unfamiliar objects. *Cognition, 68,* B41-B51. doi:10.1016/S0010-0277(98)00044-4

Koenig, M. A., & Harris, P. L. (2005). Preschoolers mistrust ignorant and inaccurate speakers. *Child Development, 76,* 1261-1277. doi:10.1111/j.1467-8624.2005.00849.x

Köhler, W. (1947). *Gestalt psychology* (2nd edn.). New York: Liveright Publishing.

Kroliczak, G., & Frey, S. H. (2009). A common network in the left cerebral hemisphere represents planning of tool use pantomimes and familiar intransitive gestures at the hand-independent level. *Cerebral Cortex, 19,* 2396-2410. doi:10.1093/cercor/bhn261

Kroliczak, G., Piper, B. J., & Frey, S. H. (2011). Atypical lateralization of language predicts cerebral asymmetries in parietal gesture representations. *Neuropsychologia, 49,* 1698-1702. doi:10.1016/j.neuropsychologia.2011.02.044

Lake, D. A., & Bryden, M. P. (1976). Handedness and sex-differences in hemispheric asymmetry. *Brain and Language, 3,* 266-282. doi:10.1016/0093-934X(76)90022-5

Landau, B., & Gleitman, L. R. (1985). *Language and experience: Evidence from the blind child.* Cambridge, MA: Harvard University Press.

Lausberg, H., Davis, M., & Rothenhäuser, A. (2000). Hemispheric specialization in spontaneous gesticulation in a patient with callosal disconnection. *Neuropsychologia, 38*, 1654-1663. Doi:10.1016/S0028-3932(00)00071-3

Lausberg, H., Zaidel, E., Cruz, R. F., & Ptito, A. (2007). Speech-independent production of communicative gestures: Evidence from patients with complete callosal disconnection. *Neuropsychologia, 45,* 3092-3104. doi:10.1016/j.neuropsychologia.2007.05.010

Law, J., Rush, R., Schoon, I., & Parsons, S. (2009). Modeling developmental language difficulties from school entry into adulthood: literacy, mental health, and employment outcomes. *Journal of Speech, Language and Hearing Research, 52,* 1401-1416. doi:10.1044/1092-4388(2009/08-0142)

Leask, S. J., & Beaton, A. A. (2007). Handedness in Great Britain. *Laterality, 12,* 559-572. doi:10.1080/13576500701541936

Liszkowski, U., Brown, P., Callaghan, T., Takada, A., & de Vos, C. (2012). A prelinguistic gestural universal of human communication. *Cognitive Science, 36,* 698-713. doi:10.1111/j.1551-6709.2011.01228.x

Liszkowski, U., Carpenter, M., Striano, T., & Tomasello, M. (2006). 12- and 18-month-olds point to provide information for others. *Journal of Cognition and Development, 7,* 173-187. doi:10.1207/s15327647jcd0702_2

Liu, J., Golinkoff, R. M., & Sak, K. (2001). One cow does not an animal make: Young children can extend novel words at the superordinate level. *Child Development, 72,* 1674-1694. doi:10.1111/1467-8624.00372

Locke, J. L., Bekken, K. E., McMinn-Larson L., & Wein, D. (1995). Emergent control of manual and vocal motor activity in relation to the development of speech. *Brain and Language, 51,* 498-508. doi:10.1006/brln.1995.1073

MacKenzie, H., Curtin, S., & Graham, S. A. (2012). 12-month-olds' phonotactic knowledge guides their word-object mappings. *Child Development, 83,* 1129-1136. doi:10.1111/j.1467-8624.2012.01764.x

Maguire, M. J., Hirsh-Pasek, K., Golinkoff, R. M., & Brandone, A. C. (2008). Focusing on the relation: fewer exemplars facilitate children's initial verb learning and extension. *Developmental Science, 11,* 628-634. doi:10.1111/j.1467-7687.2008.00707.x

Maguire, M. J., Hirsh-Pasek, K., Golinkoff, R. M., Imai, M., Haryu, E., Vanegas, S., Okada, H., Pulverman, R., & Sanchez-Davis, B. (2010). A developmental shift from similar to language-specific strategies in verb acquisition: A comparison of English, Spanish, and Japanese. *Cognition, 114,* 299-319. doi:10.1016/j.cognition.2009.10.002

Markman, E. M., & Wachtel, G. F. (1988). Children's use of mutual exclusivity to constrain the meanings of words. *Cognitive Psychology, 20,* 121-157. doi:10.1016/0010-0285(88)90017-5

Marshall, J., Best, W., Cocks, N., Cruice, M., Pring, T., Bulcock, G., Creek, G., Eales, N., Mummery, A. L., Matthews, N., & Caute, A. (2012). Gesture and naming therapy for people with severe aphasia: a group study. *Journal of Speech, Language and Hearing Research, 55,* 726-738. doi:10.1044/1092-4388(2011/11-0219)

Matthews, D., Behne, T., Lieven, E., & Tomasello, M. (2012). Origins of the human pointing gesture: a training study. *Developmental Science, 15,* 817-829. doi:10.1111/j.1467-7687.2012.01181.x

McGregor, K. K., Rohlfing, K. J., Bean, A., & Marschner, E. (2009). Gesture as a support for word learning: The case of under. *Journal of Child Language, 36,* 807-828. doi:10.1017/S0305000908009173

McManus, I. C., Sik, G., Cole, D. R., Mellon, A. F., Wong, J., & Kloss, J. (1988). The development of handedness in children. *British Journal of Developmental Psychology, 6,* 257-273. doi:10.1111/j.2044-835X.1988.tb01099.x

McNeil, N. M., Alibali, M. W., & Evans, J. L. (2000). The role of gesture in children's comprehension of spoken language: now they need it, now they don't. *Journal of Nonverbal Behaviour, 24,* 131-150. doi:10.1023/A:1006657929803

McNeill, D. (1985). So you think gestures are nonverbal? *Psychological Review, 92,* 350-371. doi:10.1037//0033-295X.92.3.350

McNeill, D. (1992). Hand and mind: What gestures reveal about thought: Chicago: University of Chicago Press.

Meguerditchian, A., & Vauclair, J. (2009). Contrast of hand preferences between communicative gestures and non-communicative actions in baboons: Implications for the origins of hemispheric specialization for language. *Brain and Language, 108,* 167-174. doi:10.1016/j.bandl.2008.10.004

Michel, G. F., Tyler, A. N., Ferre, C., & Sheu, C. F. (2006). The manifestation of infant hand-use preferences when reaching for objects during the seven- to thirteen-month age period. *Developmental Psychobiology, 48,* 436-443. doi:10.1002/dev.20161

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1993). Language-acquisition and cerebral specialization in 20-month-old infants. *Journal of Cognitive Neuroscience, 5,* 317-334. doi:10.1162/jocn.1993.5.3.317

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1997). Language comprehension and cerebral specialization from 13 to 20 months. *Developmental Neuropsychology, 13,* 397-445. doi:10.1080/87565649709540685

Mills, D. L., Conboy, B., & Paton, C. (2005). Do changes in brain organization reflect shifts in symbolic functioning? In L. L. Namy (Ed.). *Symbol Use and Symbolic Representation: Developmental and Comparative Perspectives* (pp. 123-153). Mahwah: Lawrence Erlbaum Associates.

Mol, L., & Kita, S. (2012). Gesture structure affects syntactic structure in speech. *In N. Miyake, D. Peebles & R. P. Cooper (Eds.), Proceedings of the 34th Annual Conference of the Cognitive Science Society (pp. 761-766).* Austin, TX: Cognitive Science Society.

Moll, J., de Oliveira-Souza, R., Passman, L. J., Cunha, F. C., Souza-Lima, F., & Andreiuolo, P. A. (2000). Functional MRI correlates of real and imagined tool-use pantomimes. *Neurology, 54,* 1331-1336. doi:10.1212/WNL.54.6.1331

Morford, M., & Goldin-Meadow, S. (1992). Comprehension and production of gesture in combination with speech in one-word speakers. *Journal of Child Language, 19,* 559-580. doi:10.1017/S0305000900011569

Mullen, E. M. (1995). *Mullen Scales of Early Learning* (AGS ed.). Circle Pines, MN: American Guidance Service Inc.

Mumford, K. H., & Kita, S. (2010). *Helping hands: Recognising iconicity in gestures and its advantage during verb acquisition.* Unpublished master's thesis, University of Birmingham, England.

Mumford, K. H., & Kita, S. (2011). *Helping hands: recognising iconicity in gestures and its advantage during verb acquisition.* Poster presented at the 12th International Congress for the study of child language, Montreal, Canada.

Naigles, L. (1990). Children use syntax to learn verb meanings. *Journal of Child Language, 17*, 357-374. doi: 10.1017/S0305000900013817

Namy, L. L. (2008). Recognition of iconicity doesn't come for free. *Developmental Science, 11,* 841–846. doi:10.1111/j.1467-7687.2008.00732.x

Namy, L. L., Campbell, A. L., & Tomasello, M. (2004). The changing role of iconicity in non-verbal symbol learning: A U-shaped trajectory in the acquisition of arbitrary gestures. *Journal of Cognition and Development, 5,* 37-57. doi:10.1207/s15327647jcd0501_3

Nelson, K. (1988). Constraints on word learning? *Cognitive Development, 3,* 221-246. doi:10.1016/0885-2014(88)90010-X

Nichelli, P., Grafman, J., Pietrini, P., Clark, K., Lee, K. Y., & Miletich, R. (1995). Where the brain appreciates the moral of a story. *Neuroreport, 6,* 2309-2313. doi:10.1097/00001756-199511270-00010

Nicholls, M. E. R., & Searle, D. A. (2006). Asymmetries for the visual expression and perception of speech. *Brain and Language, 97,* 322-331. doi:10.1016/j.bandl.2005.11.007

Nicoladis, E. (2002). Some gestures develop in conjunction with spoken language development and others don't: Evidence from bilingual preschoolers. *Journal of Nonverbal Behavior, 26,* 241-266. doi:10.1023/A:1022112201348

Nuckolls, J. B. (1999). The case for sound symbolism. *Annual Review of Anthropology, 28,* 225-252. doi:10.1146/annurev.anthro.28.1.225

O'Neill, D. K., Topolovec, J., & Stern-Cavalcante, W. (2002). Feeling sponginess: The importance of descriptive gestures in 2- and 3- year old children's acquisition of adjectives. *Journal of Cognition and Development, 3,* 243-277. doi:10.1207/S15327647JCD0303_1

O'Reilly, A. W. (1995). Using representations- Comprehension and production of actions with imagined objects. *Child Development, 66,* 999-1010. doi:10.1111/j.1467-8624.1995.tb00918.x

Obermeier, C., Dolk, T., & Gunter, T. C. (2012). The benefit of gestures during communication: Evidence form hearing and hearing-impaired individuals. *Cortex, 48,* 857-870. doi:10.1016/j.cortex.2011.02.007

Ofen, N., Chai, X. Q. J., Schuill, K. D. I., Whitfield-Gabrieli, S., & Gabrieli, J. D. E. (2012). The development of brain systems associated with successful memory retrieval of scenes. *Journal of neuroscience, 32,* 10012-10020. doi:10.1523/JNEUROSCI.1082-11.2012

Orlansky, M. D., & Bonvillian, J. D. (1984). The role of iconicity in early sign language acquisition. *Journal of Speech and Hearing Disorders, 49,* 287-292.

Özçalışkan, Ş., Gentner, D., & Goldin-Meadow, S. (2013). Do iconic gestures pave the way for children's early verbs? *Applied Psycholinguistics,* 1-20. doi:10.1017/S0142716412000720

Özçalışkan, Ş., & Goldin-Meadow, S. (2005). Gesture is at the cutting edge of early language development. *Cognition, 96,* B101-B113. doi:10.1016/j.cognition.2005.01.001

Özçalışkan, Ş., & Goldin-Meadow, S. (2009). When gesture-speech combinations do and do not index linguistic change. *Language and Cognitive Processes, 24,* 190-217. doi:10.1080/01690960801956911

Papadatou-Pastou, M., Martin, M., Munafo, M. R., & Jones, G. V. (2008). Sex differences in left-handedness: a meta-analysis of 144 studies. *Psychological Bulletin, 134,* 677-699. doi:10.1037/a0012814

Papafragou, A. (2010). Source-goal asymmetries in motion representation: Implications for language production and comprehension. *Cognitive Science, 34,* 1064-1092. doi:10.1111/j.1551-6709.2010.01107.x

Papeo, L., Negri, G. A. L., Zadini, A., & Rumiati, R. I. (2010). Action performance and action-word understanding: evidence of double dissociations in left-damaged patients. *Cognitive Neuropsychology, 27,* 428-461. doi:10.1080/02643294.2011.570326

Papeo, L., & Rumiati, R. I. (2013). Lexical and gestural symbols in left-damaged patients. *Cortex, 49,* 1668-1678. doi:10.1016/j.cortex.2012.09.003

Parise, E., Handl, A., Palumbo, L., & Friederici, A. D. (2011). Influence of eye gaze on spoken word processing: an ERP study with infants. *Child Development, 82,* 842-853. doi:10.1111/j.1467-8624.2010.01573.x

Paulesu, E., Vallar, G., Berlingeri, M., Signorini, M., Vitali, P., Burani, C., Perani, D., & Fazio, F. (2009). Supercalifragilisticexpialidocious: how the brain learns word never heard before. *Neuroimage, 45*, 1368-1377. doi:10.1016/j.neuroimage.2008.12.043

Pine, K. J., Bird, H., & Kirk, E. (2007). The effects of prohibiting gestures on children's lexical retrieval ability. *Developmental Science, 10*, 747-754. doi:10.1111/j.1467-7687.2007.00610.x

Price, C. J., Wise, R. J. S., Warburton, E. A., Moore, C. J., Howard, D., Patterson, K., Frackowiak, R. S. J., & Friston, K. J. (1996). Hearing and saying- the functional neuro-anatomy of auditory word processing. *Brain, 119,* 919-931. doi:10.1093/brain/119.3.919

Pruden, S. M., Hirsh-Pasek, K., Golinkoff, R. M., & Hennon, E. A. (2006). The birth of words: Ten-month-olds learn words through perceptual salience. *Child Development, 77*, 266-280. doi:10.1111/j.1467-8624.2006.00869.x

Quine, W. V. O. (1960). *Word and Object*. MIT Press.

R Core Team (2013). *R: A language and environment for statistical computing. R Foundation for Statistical Computing*, Vienna, Austria. Version 3.0.1 (Good Sport).

Ramsay, D. S., (1984). Onset of duplicated syllable babbling and unimanual handedness in infancy: Evidence for developmental change in hemispheric specialization? *Developmental Psychology, 20*, 64-71. doi:10.1037/0012-1649.20.1.64

Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. Annals of the New York Academy of Sciences, 299, 355-369. **d**oi:10.1111/j.1749-6632.1977.tb41921.x

Rauscher, F. H., Krauss, R. M., & Chen, Y. S. (1996). Gesture, speech, and lexical access: The role of lexical movements in speech production. *Psychological Science, 7,* 226-231. doi:10.1111/j.1467-9280.1996.tb00364.x

Ravizza, S. (2003). Movement and lexical access: Do non-iconic gestures aid in retrieval? *Psychonomic Bulletin & Review, 10,* 610-615. doi:10.3758/BF03196522

Rohlfing, K. J. (2006). Facilitating the acquisition of UNDER by means of IN and ON- a training study in Polish. *Journal of Child Language, 33,* 51-69. doi:10.1017/S0305000905007257

Rohlfing, K. J., Longo, M. R., & Bertenthal, B. I. (2012). Dynamic pointing triggers shifts of visual attention in young infants. *Developmental Science, 15,* 426-435. doi:10.1111/j.1467-7687.2012.01139.x

Rose, M. (2013). Releasing the constraints on aphasia therapy: the positive impact of gesture and multimodality treatments. *American Journal of Speech-Language Pathology, 22,* S227-S239. doi:10.1044/1058-0360(2012/12-0091)

Rose, M., & Sussmilch, G. (2008). The effects of semantic and gesture treatments on verb retrieval and verb use in aphasia. *Aphasiology, 22,* 691-706. doi:10.1080/02687030701800800

Roseberry, S., Hirsh-Pasek, K., Parish-Morris, J., & Golinkoff, R. M. (2009). Live action: Can young children learn verbs from video*? Child Development, 80,* 1360-1375. doi:10.1111/j.1467-8624.2009.01338.x

Rosenthal, R., & Fode, K. L. (1963). The effect of experimenter bias on the performance of the albino-rat. *Behavioral Science, 8,* 183-189. doi:10.1002/bs.3830080302

Rowe, M. L., & Goldin-Meadow, S. (2009). Early gesture selectively predicts later language learning. *Developmental Science, 12*, 182-187. doi:10.1111/j.1467-7687.2008.00764.x

Sabbagh, M. A., & Baldwin, D. A. (2001). Learning words from knowledgeable versus ignorant speakers: Links between preschoolers' theory of mind and semantic development. *Child Development, 72,* 1054-1070. doi:10.1111/1467-8624.00334

Sandhofer, C. M., Smith, L. B., & Luo, J. (2000). Counting nouns and verbs in the input: differential frequencies, different kinds of learning? *Journal of Child Language, 27,* 561-585. doi:10.1017/S0305000900004256

Schwartz, G.E., Davidson, R.J., & Maer, F. (1975). Right hemisphere lateralization for emotion in human brain- interactions with cognition. *Science, 190,* 286-288.

Scofield, J., & Behrend, D. A. (2007). Two-year-olds differentially disambiguate novel words and facts. *Journal of Child Language, 34,* 875-889. doi:10.1017/S0305000907008100

Sekine, K., Rose, M., Foster, A., Attard, M., & Lanyon, L. (2013). Gesture production patterns in aphasic discourse: In-depth description and preliminary predictions. *Aphasiology, 27,* 1031-1049. doi:10.1080/02687038.2013.797067

Seston, R., Golinkoff, R. M., Ma, W. Y., & Hirsh-Pasek, K. (2009). Vacuuming with my mouth?: Children's ability to comprehend novel extensions of familiar verbs. *Cognitive Development, 24,* 113-124. doi:10.1016/j.cogdev.2008.12.001

Skipper, J. I., Goldin-Meadow, S., Nusbaum, H. C., & Small, S. L. (2007). Speech associated gestures, Broca's area and the human mirror system. *Brain and Language, 101,* 260-277. doi:10.1016/j.bandl.2007.02.008

Sommer, I. E. C., Aleman, A., Bouma, A., & Kahn, R. S. (2004). Do women really have more bilateral language representation than men? A meta-analysis of functional imaging studies. *Brain, 127,* 1845-1852. doi:10.1093/brain/awh207

Straube, B., Green, A., Bromberger, B., & Kircher, T. (2011). The differentiation of iconic and metaphonic gestures: Common and unique integration processes. *Human Brain Mapping, 32,* 520-533. doi:10.1002/hbm.21041

Szaflarski, J. P., Rajagopal, A., Altaye, M., Byars, A. W., Jacola, L., Schmithorst, V. J., Schapiro, M. B., Plante, E., & Holland, S. K. (2012). Left-handedness and language lateralization in children. *Brain Research, 1433,* 85-97. doi:10.1016/j.brainres.2011.11.026

Taylor, K. I., & Regard, M. (2003). Language in the right cerebral hemisphere: Contributions from reading studies. *News in Psychological Sciences, 18,* 257-261.

Tellier, M. (2007). How do teacher’s gestures help young children in second language acquisition? *Proceedings of the meeting of International Society of Gesture Studies, ISGS 2005: Interacting Bodies, June 15–18, ENS Lyon,* France. http://gesture-lyon2005.ens-lsh.fr/IMG/pdf/TellierFINAL.pdf

Tellier, M. (2008). The effect of gestures on second language memorisation by young children. *Gesture, 8,* 219-235. doi:10.1075/gest.8.2.06tel

Thompson, L. A., & Massaro, D. W. (1986). Evaluation and integration of speech and pointing gestures during referential understanding. *Journal of Experimental Child Psychology, 42,* 144-168. doi:10.1016/0022-0965(86)90020-2

Thompson, R. L., Vinson, D. P., Woll, B., & Vigliocco, G. (2012). The road to language learning is iconic: Evidence from British Sign Language. *Psychological Science, 23,* 1443-1448. doi:10.1177/0956797612459763

Tomasello, M. (2008). *Origins of Human Communication.* MIT Press.

Tomasello, M., Striano, T., & Rochat, P. (1999). Do children use objects as symbols? *British Journal of Developmental Psychology, 17,* 563-584. doi:10.1348/026151099165483

Vaish, A., Demir, O. E., & Baldwin, D. (2011). Thirteen- and 18-month-old infants recognize when they need referential information. *Social Development, 20,* 431-449. doi:10.1111/j.1467-9507.2010.00601.x

Valenzeno, L., Alibali, M. W., & Klatzky, R. (2003). Teachers' gestures facilitate students' learning: A lesson in symmetry. *Contemporary Educational Psychology, 28,* 187-204. doi:10.1016/S0361-476X(02)00007-3

Vauclair, J., & Imbault, J. (2009). Relationship between manual preferences for object manipulation and pointing gestures in infants and toddlers. *Developmental Science, 12,* 1060-1069. doi:10.1111/j.1467-7687.2009.00850.x

Vingerhoets, G., Alderweieldt, A.S., Vandemaele, P., Cai, Q., Van der Haegen, L., Brysbaert, M., & Achten, E. (2013). Praxis and language are linked: Evidence from co-lateralization in individuals, with atypical language dominance. *Cortex, 49,* 172-183.

Waxman, S. R., Lidz, J. L., Braun, I. E., & Lavin, T. (2009). Twenty four-month old infants' interpretations of novel verbs and nouns in dynamic scenes. *Cognitive Psychology, 59,* 67-95. doi:10.1016/j.cogpsych.2009.02.001

Werner, H., & Kaplan, B. (1963). *Symbolic formation: An organismic-developmental approach to language and the expression of thought.* New York: Wiley.

Wernicke C. (1874). Der aphasische Symptomenkomplex. Breslau: Cohn & Weigert.

Wheaton, L. A., & Hallett, M. (2007). Ideomotor apraxia: A review. *Journal of the Neurological Sciences, 260,* 1-10. doi:10.1016/j.jns.2007.04.014

Whitehouse, A. J. O., & Bishop, D. V. M. (2008). Cerebral dominance for language function in adults with specific language impairment or autism. *Brain, 131,* 3193-3200. doi:10.1093/brain/awn266

Wilkinson, K. M., & Hennig, S. (2007). The state of research and practice in augmentative and alternative communication for children with developmental/ intellectual disabilities. *Mental Retardation and Developmental Disabilities Research Reviews, 13,* 58-69. doi:10.1002/mrdd.20133

Willems, R. M., Özyürek, A., & Hagoort, P. (2007). When language meets action: The neural integration of gesture and speech. *Cerebral Cortex, 17,* 2322-2333. doi:10.1093/cercor/bhl141

Wittek, A. (2002). *Learning the meaning of change-of-state verbs: A case study of German child language.* Berlin: Mouton de Gruyter.

Wu, Y. C., & Coulson, S. (2007). How iconic gestures enhance communication: An ERP study. *Brain and Language, 101,* 234-245. doi:10.1016/j.bandl.2006.12.003

Xu, J., Gannon, P. J., Emmorey, K., Smith, J. F., & Braun, A. R. (2009). Symbolic gestures and spoken language are processed by a common neural system. *Proceedings of the National Academy of Sciences of the United States of America, 106,* 20664-20669. doi:10.1073/pnas.0909197106

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology- General, 135,* 1-11. doi:10.1037/0096-3445.135.1.1

LIST OF APPENDICES

APPENDIX 1

The twelve manner actions used in the experiments described in Chapter 3, organised into six video groups.

Video Group	Manner	Description of action
1	Rolling	Use roller to roll on paint
	Printing	Use sponge to print on paint
2	Flipping	Use thumb and fingers to flip over sections of white icing to reveal a black background.
	Cutting	Use metal cutters to remove sections of icing to reveal a black background
3	Gathering	Use thumb and fingers to gather up gravel to reveal a black background
	Brushing	Use toothbrush to organise gravel to reveal a black background

4	Unravelling	Unravel black material to create a pattern on a white background
	Sticking	Use block of wood with Velcro to remove bits of material to reveal a pattern
5	Placing	Place pieces of pre-sprinkled card
	Sprinkling	Sprinkle black powder paint
6	Clearing	Move small bits of foam to reveal black areas
	Pushing	Push small bits of foam with fingers and thumb

Note that, video groups 2 and 4 were omitted from the main experiment in Chapter 3.

APPENDIX 2

The iconic manner and end state gestures associated with each action used in Chapter 3.

Manner	Iconic Manner Gesture	Iconic End State Gesture (Stripes)	Iconic End State Gesture (Triangle)
Cutting Printing Placing Sticking	Hand as if holding object and vertical movements.	Finger and thumb separated from fist making vertical movements	Finger and thumb on both hands used to form a triangle
Flipping Sprinkling Gathering Pushing	Hand with fingers pointing downwards, thumb and other four fingers move towards and away from each other.	Vertical palm moving sideways, as if tips of fingers tracing the stripes	Index Finger moving in a triangle
Clearing Brushing Unravelling Rolling	Hand as if holding thin object and quick motion away from the body.	Index finger moving in vertical lines	Two palms with tips of fingers together and thumbs together used to form a triangle.

The gestures for end state all displayed that end-state on the vertical axis (rather than horizontal axis). Triangles were used rather than just points, due to decreased performance in these trials in a pilot test with adults.

Note that the following actions were not used in the main experiment in Chapter 3: cutting, flipping, unravelling and sticking.

APPENDIX 3

Details of the pre-test in Chapter 3

Participants

The pre-test consisted of two age groups: twenty-four 3-year-olds (11 females and 13 males; *M*=42.02months, *SD*=3.30) and twenty-four adults (22 females and two males; *M*=19.58 years, *SD*=1.02). Three-year-old participants were recruited from nurseries in Warwickshire, England, and received a sticker in return for their participation. None of the children in the pre-test also participated in the main experiment. Adult participants were recruited from the University of Birmingham, England, and received course credit in return for their participation.

One adult participant was excluded as she responded: '*Neither*', on 5 out of the 12 trials.

Design

The pre-test used a mixed design. The between-subject independent variable was age (2 levels: 3-years and adult). The within-subject independent variable was the type of gesture (2 levels: manner and end-state). The dependent variable was binary, either correct of not.

Stimuli

The practice stimuli consisted of eight still photos of familiar objects. The experimental stimuli consisted of 24 video clips, each lasting between 7-16 seconds. All videos started with a white piece of paper on a table and black material was either added, or revealed, to leave an end state of either black and white stripes, or a black triangle on a white background.

There were 12 different manners used in the study, such as printing and rolling. Each manner was used in two videos: one resulting in a stripy end state, and one resulting in a triangular end state. Details of all the video clips can be found in Appendix 1.

The 12 manners were organised into six video groups. These were selected such that the end states were as similar as possible to each other. For example, printing and rolling were a video group as they both used black paint to accomplish the end state. The video groups were also designed such that iconic gestures depicting the two manners in a given group were distinct. Each video group was made of four video clips in total (two manners x two end states).

In the experiment two videos would play simultaneously, side-by-side during trials. The videos that were shown together were taken from within a video group, and between them showed the two different manners and end states. See Figure 1 for an example of two videos that were shown together. The videos that were shown together were matched for length, within one second.

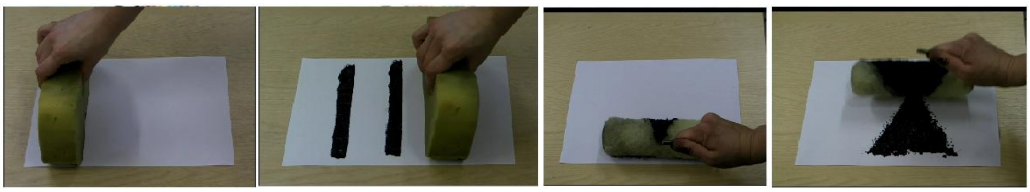


Figure 1. Example of two videos that would be shown in one trial.

Gestures

The study used two types of iconic gestures: manner and end state. Each of the 12 manners could be depicted by one of three iconic manner gestures, which depicted the motion of the hand in the video. Similarly, each of the end states could be depicted by one of three iconic end state gestures. Details of all the iconic gestures can be found in Appendix 2.

Counterbalancing

Across participants, all 24 videos appeared equally often as the target and as the distracter. Further, the video groups were rotated so that across participants they appeared equally often in all the trials. Each participant saw all six video groups twice, such that they saw all 24 videos. Each participant was asked equally about gestures that depicted manner and end state, and also about gestures that depicted triangular and striped end states. This resulted in 24 counterbalancing groups (six orders of video groups x two types of end states x two types of gesture). Finally, the correct choice appeared equally often in the left and right position.

Procedure

Three-year-old participants were tested individually in a quiet area of their own nursery, and adult participants were tested individually in a quiet room at the University. For 3-year-old participants stimuli were presented on a 20” screen and for adult participants stimuli were presented on a 10.1” netbook screen. Adult participants were unaware that this experiment also included a 3-year-old group.

Practice Phase

Only 3-year-old participants saw the practice trials. The practice phase involved four trials. Participants were asked to point to familiar objects from a pair of still images (e.g. '*which one's a duck?*'). This was to practice the pointing process. There was no practice of matching gestures to videos so that participants were not primed to attend to a particular aspect of the video (e.g. end state or manner) before the experimental phase. Targets in this phase appeared equally in the left and right position to encourage children to consider both positions as a correct answer. If children failed to make a spontaneous pointing gesture the experimenter asked '*Can you point to it for me?*' Feedback and encouragement was given during this phase.

Experimental Phase

Each participant saw 12 experimental trials: two trials per group of videos. They were shown six manner gestures (two of each type, all resulting in one particular end state) and six end-state gestures (all resulting in one particular end state, and seeing the corresponding gestures twice each). These were organised into four blocks of three trials. One participant, for example, may see the three manner gestures (for the target video resulting in a triangle), followed by the three stripy end-state gestures, followed by the three manner gestures again (resulting in a triangle) and finally the three stripy end-state gestures again.

At the start of each trial the experimenter said: '*Let's see what happening here*'. Two videos would begin playing simultaneously side-by-side. These videos were taken from one video group, which between them depicted two different manners and end states (e.g. printing stripes and rolling a triangle, see Figure 1). As the videos were playing for the first time, the experimenter said: '*one of these is like this*' *(*plus either an iconic manner gesture or an iconic end-state gesture*)*. The videos then looped. During the second playing of the videos, the experimenter asked '*Which one is like this (*plus iconic gesture*)?*' This was the same iconic gesture that they saw with the first sentence. The question was asked while the videos were playing to reduce memory load for the children, and was asked as the videos played for the second time to ensure that participants had seen both manners and both end states before making their decision.

If participants responded before being asked *'Which one is like this?'* the experimenter did not respond to their choice (although it was noted), instead the participants were encouraged to watch the videos, and were required to choose again after hearing the question. If participants did not respond they were encouraged to point ('*can you point to it for me?*'), to remind them of the correct response. Trials ended when participants had responded after the question had been asked, or after the question (and iconic gesture) had been repeated five times.

Data Analysis

An alpha level of .05 was used in all statistical tests. One trial was removed as a child picked a video before being shown the iconic gesture. One trial was also removed as a child did not make a decision.

Results and discussion

Comparison of correct vs. initial correct for three year-olds participants

On 111 (out of 288) trials children selected a video after seeing the gesture for the first time, before they had watched the videos in full and before they had been asked the question.

Children were required to point again after they had heard the question. In 86 of these 111 trials children selected the same video before and after the question; in 25 trials children changed their choice after they heard the question. The proportion of correct responses 3-year-olds made initially (*M*= .68) and after the question was asked (*M*= .67) was compared using a paired-samples *t*-test. The results showed that there was no difference between the measure used (p>.1). The rest of the analysis, therefore, will use the proportion of correct responses after the question was asked.

Analysis of gesture type and age

The purpose of the experiment was not to investigate differences between stripes and triangles, so the data was collapsed across these two end states. As the dependent variable was binary, such that on each trial, participants could either be correct or incorrect, the data was analysed using a generalised linear mixed effect model. See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013).

Two models were compared to assess whether there was an interaction between age and gesture type. The first model included the following fixed effects: gesture type (end state and manner), age group (adult and 3-year-olds) and the interaction between the gesture type and age group. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for gesture type (but not age since this was between participants), 3) correlations between the random intercept by participant and the random slope by participant for gesture type.

The second model was the same except that only the fixed effects for gesture type and age group were included; the interaction between gesture type and age group was not included.

The results from comparing the two models using a likelihood ratio test showed that the interaction between gesture type and age group was not significant (χ^2 (1) = 1.168, p>.1). See Figure 2 for the descriptive results. Table 1 reports the parameters of the model without the interaction (Model 1).

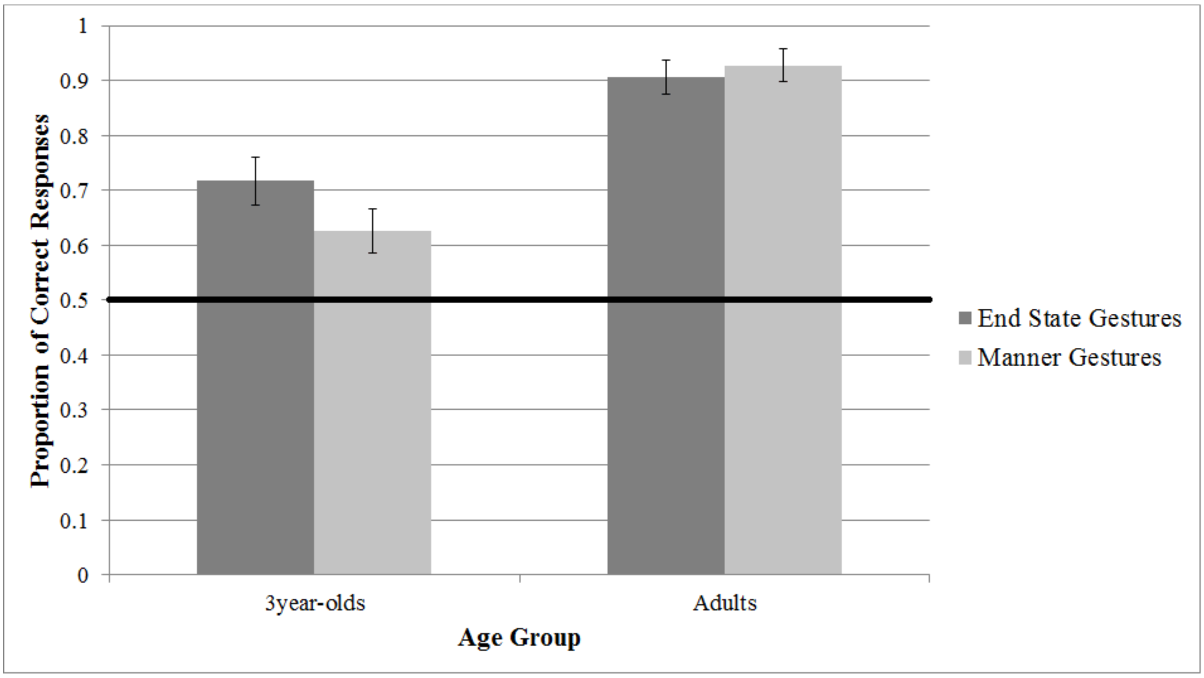


Figure 2. The mean proportion of correct responses, in the gesture-video matching task, for adults and 3-year-olds, for end-state and manner gestures. The thick line represents chance (.5) and the error bars show standard error of the participant means.

Table 1

Fixed effects of Model 1 (fixed effects of gesture type and age group but not the interaction)

	B	*SE*	*z*	*p*
Intercept	3.714	0.412	9.025	<.001
Gesture Type	-0.3619	0.262	-1.383	.167
Age Group	-0.9218	0.148	-6.213	<.001

In order to test whether there was a main effect of age two further models were used. The first model included age as a fixed effect. The model also included random intercepts by participant. The second model only included a constant and random intercepts by participant. The results from the likelihood ratio test revealed a significant effect of age (χ^2 (1) = 32.924, p<.001). This is such that adults performed better than children. Table 2 reports the parameters of the model including the fixed effect of age group (Model 2).

Table 2

Fixed effects of Model 2 (fixed effect of age group)

	B	*SE*	*z*	*p*
Intercept	3.375	0.374	9.021	<.001
Age Group	-0.877	0.145	-6.050	<.001

Finally, in order to test whether there was a main effect of gesture type two additional models were used. The first model included gesture type as a fixed effect. The model also included random intercepts by participant, random slopes by participant for gesture type and the correlations between the random intercept by participant and the random slope by participant for gesture type. The second model only included a constant and the same random effect structure as the first. The results from the likelihood ratio test revealed no effect of gesture type (χ^2 (1) = 0.452, p>.1).

Comparison to chance

Next the data was split by age groups and by gesture type, and the proportion of correct responses was compared to chance (.5) using planned *t*-tests. The results showed both groups performed significantly better than chance for both gesture types: adult end-state, (t (22) = 13.04, p<.001); adult manner, (t (22) = 14.56, p<.001); child end-state, (t (23) = 4.73, p<.001) and child manner gestures (t (23) = 3.09, p=.005).

Selection of stimuli for the main experiment

The purpose of the pre-test was to select stimuli that children could match gestures to most easily, for the main experiment. Therefore, the data from 3-year-olds was examined further. The data showed that performance for manner gestures in Video Groups 2 and 4 was poorer than for other video groups, so these video groups were removed for the main experiment. Figure 3 shows a breakdown of performance per video group.

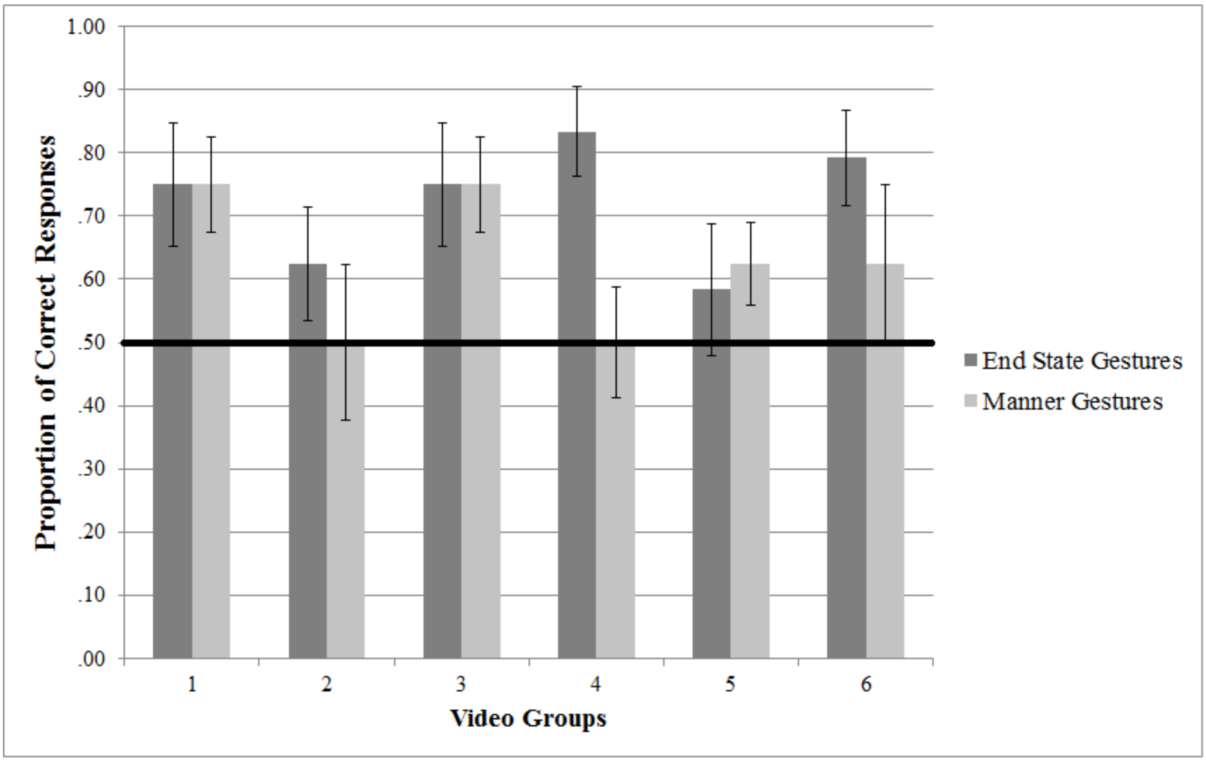


Figure 3. The mean performance for end-state and manner gestures across the six video groups. The thick line represents chance performance (0.5) and the error bars show standard error of participant means.

The data from the children and for the chosen video groups only were used to check that there was no effect of gesture in the final set of stimuli. Two models were used for comparison. The first model included the fixed effect of gesture type. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for gesture type, 3) correlations between the random intercept by participant and the random slope by participant for gesture type. The second model only included a constant, random intercepts by participant, random slopes by participant for gesture type and correlations between the random intercept by participant and the random slope by participant for gesture type. Importantly, the results from the likelihood ratio test revealed no effect of gesture type (χ^2 (1) = 1.095, *p*>.1).

Finally, performances for both end-state gestures (*t* (23) = 3.98, *p*=.001) and manner gestures (*t* (23) = 4.17, *p*<.001) were better than chance (.5).

This pre-test investigated whether children could match the iconic manner gestures and the iconic change-of-state gestures to videos depicting an action or state. The results showed that although the children did not perform at adult level, they did show the same intuition as adults. Further, they showed the same pattern as adults (at a lower level) for both gesture types. Finally, the results showed that children and adults could match these iconic gestures to videos better than chance and there was no difference between the two types of gestures (end-state or manner).

This pre-test also enabled stimuli, which children can match gestures to most easily, to be selected for use in the main experiment.

APPENDIX 4

The fourteen manner actions and end states used in the experiments described in Chapter 4, organised into seven groups.

Video Group	Manner	Description of action	End states
1	Big Brushing	Using a white spatula in slow sweeps to organise white gravel, revealing a black background.	Square and U shape
	Digging	Using a white spatula in quick vertical movements to organise white gravel, revealing a black background.	
2	Lifting	Use a block of wood (and Velcro) to place bits of black material (on white card) onto a white background .	Diamond and spiral

	Brushing	Use block of wood to brush bits of black material (on white card) onto a white background.	
3	Pinching	The index finger and thumb are used to arrange bits of black material on a white background.	Heart and three vertical lines
	Pushing	The fingers (with the thumb tucked into the palm) are used to push bits of black material on a white background.	
4	Placing	Bits of black material are placed from above onto a white background.	Cloud and three horizontal lines

	Squiggling	Using an index finger pointed hand shape and quick side-to-side movements, bits of black material are arranged on a white background.	
5	Sprinkling	Sprinkle black power paint onto a white background.	Circle and Cross (X)
	Pouring	Pouring black power held in the palm of the hand onto a white background.	
6	Rolling	Using a roller to roll black pieces of material to a white background.	Semi-circle and zigzag horizontal line
	Printing	Using a roller in vertical motions to put black pieces of material onto a white background.	

7	Pushing	Small bits of white material are quickly pushed aside using the fingers and thumb to reveal a black background.	Triangle and wavy horizontal line
	Pulling	Small bits of white material are smoothly pulled backwards using the fingers (thumb is tucked into the palm) revealed a black background.	

Note, video groups, 2 and 6 were omitted from the main experiment.

APPENDIX 5

The iconic manner and end state gestures associated with each action used in Chapter 4. For end state gestures, a pointed hand shape was always used.

Group	Manner	End state
1	*Big Brushing* Hand in a fist, fingers facing downwards, making slow, smooth movements, towards and across the body.	*Square* Using both hands, starting at the top centre of an imaginary square, they trace the outline, meeting again at the bottom centre of the square.
	Digging Hand in a fist, fingers facing upwards, making short, quick movements forwards and backwards	*U* One hand traces a U shape.
2	*Lifting* Using one hand, with fingers and thumb separated, as if holding a thin book, fingers pointing downwards, the hand moves up and slow slowly.	*Spiral* One hand traces a spiralling line, starting from the centre.

	Brushing Using one hand, with fingers and thumb separated, as if holding a thin book, fingers pointing downwards, the hand rotates at the wrist, forwards and backwards.	*Diamond* Using both hands, starting at the top point of an imaginary diamond, they trace the outline, meeting again at the bottom point of the diamond.
3	*Pinching* The index finger and thumb open and close, while the hand moves slightly up and down.	*Heart* Using both hands, starting at the dip in the top of an imaginary heart, they trace the outline, meeting again at the bottom point of the heart.
	Pushing The fingers (with the thumb tucked into the palm) make a smooth circular motion, down and away from the body and up and towards the body.	*Three vertical lines* Starting at the top of each line, the hand traces down three imaginary vertical lines, side by side.

4	*Placing* Using one hand, with fingers and thumb separated into a C shape, as if holding a wide book, the hand moves up and down slowly.	*Cloud* Using both hands, starting at the top centre of an imaginary cloud, they trace the curved outline, meeting again at the bottom centre of the cloud.
	Squiggling Using a pointed hand shape, the hand makes short, quick, side to side movements.	*Three horizontal lines* Starting at the right (from experimenter's perspective) of each line, the hand traces along three imaginary horizontal lines, above each other.
5	*Sprinkling* Fingers pointing downwards, the fingers and thumbs rub against each other.	*Circle* Using both hands, starting at the top centre of an imaginary circle, they trace the outline, meeting again at the bottom centre of the circle.

	Pouring Using a cupped upwards facing hand, the hand twists around the wrist slowly, and then returns to original position.	*Cross (X)* Starting at the top of one of the imaginary lines in an X, one hand traces the line, then traces the other line (again starting from the top).
6	*Rolling* Hand in a fist, fingers facing downwards, the hand makes a smooth circular motion, down and away from the body and up and towards the body.	*Semi-circle* Using both hands, starting at the centre of flat line at the top of an imaginary semi-circle, they trace the outline, meeting again at the bottom centre of the semi-circle.
	Printing Using one hand, with fingers and thumb separated into a C shape, as if holding a wide book, the hand moves up and down slowly.	*Zigzag horizontal line* One hand traces a horizontal zigzagged line.

7	*Pushing* Fingers and thumb are together, facing downwards, then separate outwards and back together quickly.	*Triangle* Using both hands, starting at the top point of an imaginary triangle, they trace the outline, meeting again at the bottom centre of the triangle.
	Pulling The fingers (with the thumb tucked into the palm) make a smooth circular motion, up and away from the body and down and towards the body.	*Wavy horizontal line* One hand traces a wavy horizontal line.

Note, Video Groups 2 and 6 were omitted from the main experiment.

APPENDIX 6

Details of the stimuli pre-test in Chapter 4.

Participants

Fourteen adults (12 female and two males; M= 27.0years, SD= 4.48) and 16 3-year-olds (8 females and eight males; M= 40.94months, SD=3.28), took part in the study. Adults were all postgraduate students recruited from the University of Birmingham and could claim course credits in return for participation. Children were recruited from nurseries across Warwickshire, England, and were given a sticker in return for their participation.

Design

The study used a mixed design with age as the between subject variable (2 levels: 3-years and adult) and gesture type as the within subject variable (2 levels: end state and manner). The dependent variable was binary: either correct or not.

Materials

The practice stimuli consisted of eight photos of familiar objects, such as a teddy bear, a car, a duck. The experimental trials used 28 short video clips (6-11seconds) as exemplars of novel verbs. The videos all depicted an actor's hand manipulating objects in different ways to bring about a clear end state (e.g. placing sections of black material to create a 'cloud' shape on a white background). See Appendix 4 for details of all of the videos.

The pre-test used 28 videos, ranging 6-11 seconds, and depicting 14 different manners. These manners were organised into seven video groups (1-7). For each group, each manner resulted in two different end states. There were also, therefore, 14 different end states

(2 per group). Thus, each group consisted of two video pairs: Pair 1, manner A resulting in end state A, manner B resulting in end state B; pair 2, manner A resulting in end state B and manner B resulting in end state A. These pairs of videos were shown together in a two-way forced choice task.

Note that within a group of videos, similar materials were used in all four clips, but these could be used in different ways, for example using the roller's handle to roll on a shape or holding the roller to print on a shape.

Iconic gestures

There were two types of iconic gestures: manner and end state. Manner gestures depicted the manner shown in the video and, therefore, depicted the action of the hand in the video, regardless of the state that action brought about. End state gestures depicted the shape or lines formed in the video, regardless of how that state was brought about. All gestures were produced live by the experimenter (See Appendix 5 for details of the gestures).

Pointing gestures were not used at all in order to avoid some trials being more interactive than others. It was thought that by being more interactive, performance on these trials would be altered, either for the better as motivation may be higher, or worse as they may be distracting.

As with Chapter 3, none of the manner used accomplished an end state by painting or drawing or otherwise tracing the outline of the end state, such that end state gestures could not be confused with manner gestures.

Counterbalancing

All participants saw 14 trials (two per video group). Gesture type was blocked, such that participants saw 7 trials of one type of gesture (manner or end state), followed by 7 trials of the other gesture type. The order of gesture type was counterbalanced between participants. Finally, the target appeared in the left and right locations equally often.

Between participants the order the groups of videos appeared was rotated, such that all 7 groups appeared in all trial positions (1^{st}, 2^{nd} ...) equally. All the 28 videos appeared as the target equally often. Further each video was the target in manner gesture trials and end state gesture trials equally often.

This resulted in 14 counterbalancing groups (7 video groups x 2 types of gesture).

Procedure

Participants were tested individually in a quiet area of their nursery (for children) or university (for adults). For children the stimuli were presented on a 20” screen and for adults stimuli were presented on a 10.1” netbook screen. Adult participants were not told that the experiment also included a 3-year-old group.

Practice trials

Only 3-year-old participants saw practice trials. Children saw two practice trials at the start of the study and two more after seven trials to reengage them in the experiment and to boost confidence. Participants were asked to point still images of familiar objects (e.g. ‘*which one’s a duck?*’). Practice trials aimed to familiarise children with the pointing procedure and to build confidence. Further, as the target appeared in both the left and right locations, these trials aimed to encourage children to consider both locations as the correct choice. If children failed to produce a pointing gesture, children were reminded of the correct response using the prompt: '*Can you point to it for me?*' Feedback and encouragement was given during the practice trials.

There were no practice trials of matching gestures to videos, this was because we did not want to prime children towards manner or end state.

Experimental trials

Adults were given the instruction to match the gesture to whichever video they felt matched better for whatever reason. For children, at the start of each trial, the experimenter said '*Let's see what's happening here!*' Two videos would then play simultaneously, side-by-side. These videos came from within one group of videos and together depicted both manners and both end states in that group. For example, printing a semicircle and rolling a zigzag line.

The first time the videos played the experimenter said '*one of these is like this!* (plus either an iconic manner gesture or an iconic end state gesture)'. The videos then looped and the experimenter asked '*Which one is like this?* (plus the same iconic gesture seen with the first sentence)'. The question was asked on the second viewing to ensure that participants were aware of the manner and end states for both videos before responding to the question.

Participants sometimes responded when they initially saw the gesture (in the first showing of the video). In these trials the experimenter did not respond to the choice (although it was noted) but encouraged the participants to watch the videos. Participants were still required to point again after the question had been asked.

If participants failed to produce a pointing gesture they were reminded of the correct response by the prompt: '*Can you point to it for me?*' Trials ended after the participant had made their selection after hearing the question, or after the question and the gesture had been repeated together five times.

Data Analysis

Two 3-year-old participants were removed from the analysis: one due to a side-bias, and one due to a known attentional problem. Further, one child did not give a response for one trial, so this trial was excluded. An alpha level of .05 was used in all statistical tests.

Results and discussion

Comparison of responses before and after the question, in 3-year-old participants

On 30 of the 195 trials, children pointed to a video when they saw the gesture for the first time, rather than waiting to see it a second time, when it was accompanied by the question 'Which one is like this?'. In 21 of these 30 trials children selected the same video after they had heard the question but in 9 of these 30 trials children changed their response after they heard the question. The proportion of correct responses children made initially (M=.60) and after the question was asked (M=.64) was compared using a paired samples t-test. The results revealed there was no significant difference between the measures used. Therefore the rest of the analysis will use the proportion of correct responses after the question had been asked.

Analysis of gesture type and age

As the dependent variable was binary, the data was entered into a generalised linear mixed effect model. See Jaeger (2008) for the advantage of such models. All mixed effect logistic regressions in the present study were carried out with lmer function, using the Laplace method, in the lme4 package (Bates, Maechler & Bolker, 2013) of R software (R Core Team, 2013).

In order to assess whether there was an interaction between age group and gesture type, two models were compared. The first model included the following fixed effects: gesture type (end state and manner), age group (adult and 3-year-olds) and the interaction between the gesture type and age group. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for gesture type (but not age since this was between participants), 3) correlations between the random intercept by participant and the random slope by participant for gesture type. The second model was the same except that only the fixed effects for age group and gesture type were included; the interaction between age group and gesture type was not included.

The results of a likelihood ratio test showed that there was no significant interaction between age group and gesture type (χ^2 (1) = 0.024, p>.1). See Figure 1 for the descriptive results. Table 1 reports the parameters of the model including the fixed effects of gesture type and age group (Model 1).

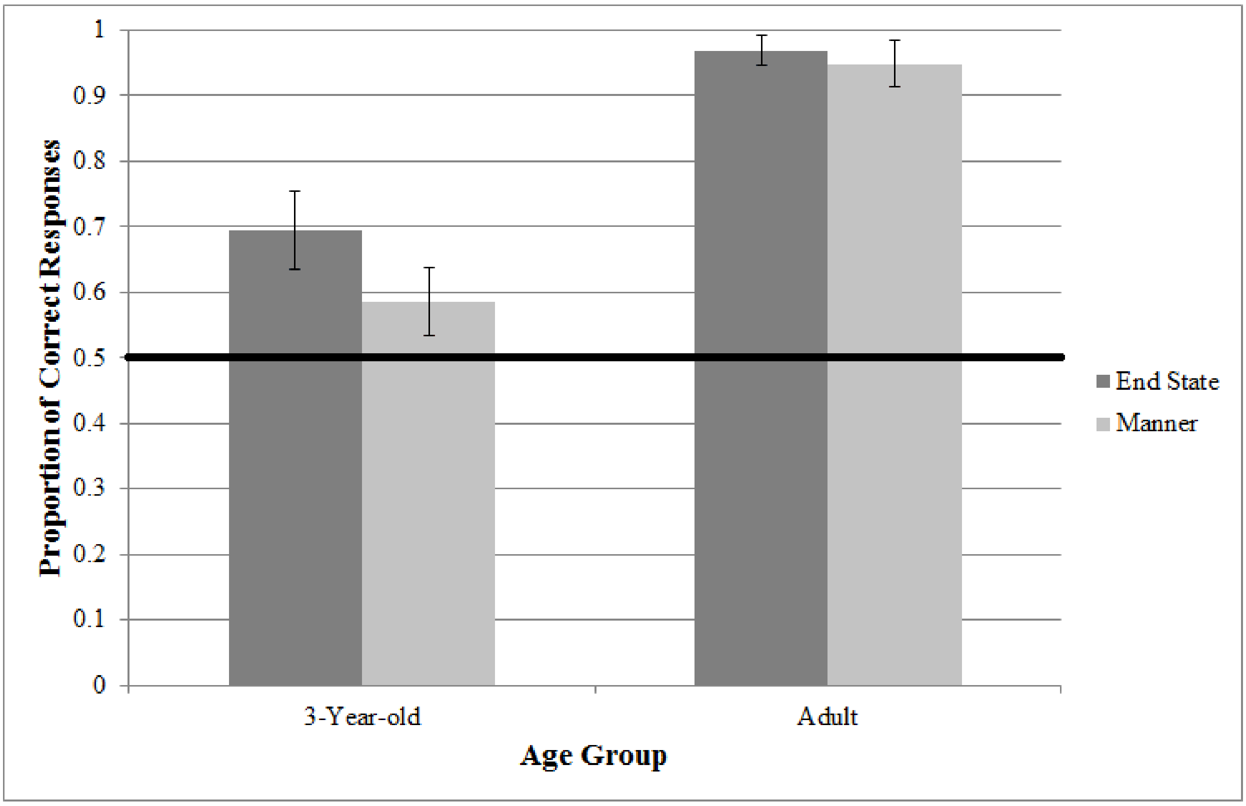


Figure 1. the proportion of correct responses for both gesture types for adults and 3-year-olds. The thick line represents chance (0.5) and the error bars represent standard error for participant means.

Table 1

Fixed effects of Model 1 (fixed effect of gesture type and age group but not the interaction between the two)

	B	*SE*	*z*	*p*
Intercept	5.246	0.686	7.645	<.001
Gesture Type	-0.598	0.464	-1.288	0.198
Age Group	-1.426	0.219	-6.505	<.001

In order to test whether there was a main effect of age two further models were used. The first model included age as a fixed effect. The model also included random intercepts by participant. The second model only included a constant and random intercepts by participant. The results from the likelihood ratio test revealed a significant effect of age (χ^2 (1) = 38.571, p<.001). This is such that adults performed better than children. Table 2 reports the parameters of the model including the fixed effect of age group (Model 2).

Table 2

Fixed effects of Model 2 (fixed effect of age group)

	B	*SE*	*z*	*p*
Intercept	4.446	0.547	8.133	<.001
Age Group	-1.289	0.195	-6.597	<.001

Finally, in order to test whether there was a main effect of gesture type two additional models were used. The first model included gesture type as a fixed effect. The model also included random intercepts by participant, random slopes by participant for gesture type and the correlations between the random intercept by participant and the random slope by participant for gesture type. The second model only included a constant and the same random effect structure as the first. The results from the likelihood ratio test revealed no effect of gesture type (χ^2 (1) = 1.080, p>.1).

Comparison to chance

Next the data was split into the two age groups and the overall proportion of correct responses was compared to chance (0.5) using planned t-tests. The results revealed that both adults (*M* = .96, *SD* = .07, *t* (13) = 23.667, *p*<.001) and children (*M* = .64, *SD* = .12, *t* (13) = 4.40, *p*=.001).

Finally, the results were split by gesture type and the comparison to chance was repeated. The results showed that adults could match both manner (*M*= *.95*, *SD* =.13, *t* (13) = 12.661, *p*<.001) and end state gestures (*M* = .97, *SD*= *.08*, *t* (13) =21.236, *p*<.001) better than chance, while children could match end state gestures better than chance (*M* = .69, *SD* = .22, *t* (13)=3.25, *p*=.006), but not manner gestures (*M* = .59, *SD* = .19, *t* (13) =1.67, *p*=.119).

Selection of stimuli for the main experiment

The primary purpose of this experiment was to select stimuli for the main experiment. As the children's performance for manner gestures for video groups 2 and 6 were descriptively poorer than other gestures so these were removed, see Figure 2.

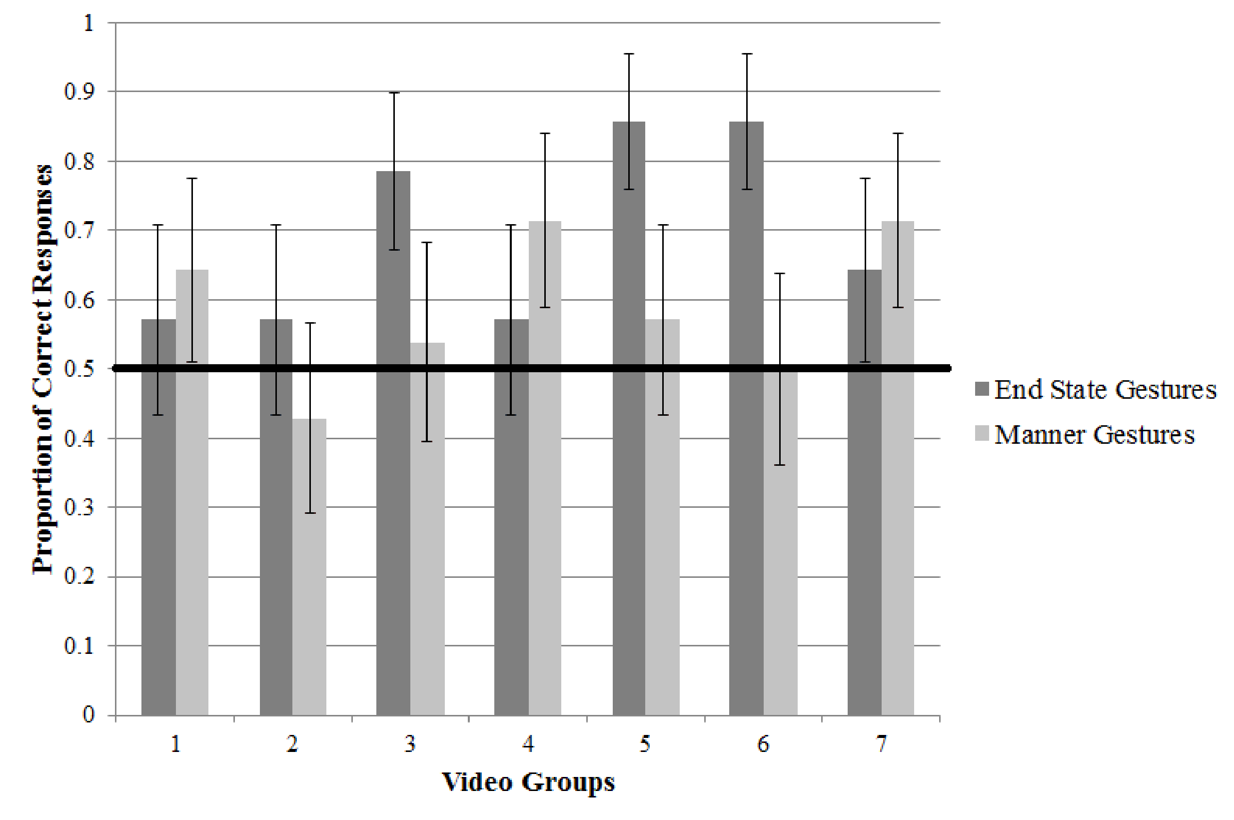


Figure 2. The mean proportion of correct responses for 3-year-old participants for all 7 video groups, for both types of gestures. The thick line represents chance (0.5) and the error bars represent standard error of participant means.

Two further models were then compared using only the data from the children and for the chosen video groups. The first model included the fixed effect of gesture type. The model also included the maximal random effect structure for participant, as suggested by Barr and colleagues (2013): 1) random intercept by participant, 2) random slopes by participant for gesture type, 3) correlations between the random intercept by participant and the random slope by participant for gesture type. The second model only included a constant and the same random effect structure as the first. The key result remained the same, specifically that there was no effect of gesture (χ^2 (1) = 0.154, p>.1), such that children could match the end state and manner gestures to the referents equally well.

Finally, the proportion of correct responses was compared to chance (0.5). Results revealed that children could match the end state gestures significantly better than chance (t (13)= 2.842, p=.014) and manner gestures marginally better than chance (t (13) = 2.002, p=.067). Therefore, the main experiment used the video groups 1, 3, 4, 5 and 7.

APPENDIX 7

Additional analysis for Chapter 4, as requested by the editor of the Journal of Child Development.

Effect of bilingualism

Six of the children in the study were acquiring additional languages. These children were removed and the remaining data was reanalysed. In order to investigate whether gesture condition effect manner bias, two generalised linear mixed effect models were compared. The first model included the fixed effect of gesture condition (end state, manner or no gesture). The model also included random intercepts by participants. The second model only included a constant and random intercepts by participants. The results from comparing the two models using a likelihood ratio test showed that there was a main effect of gesture (χ^2 (2) = 13.672, p=.001).

In order to investigate which gesture groups were performing differently from one another, we looked more closely at the first model (Model 1). Table 1 reports the parameters of this model.

Table 1

Fixed effects of Model 1 (fixed effect of gesture condition)

	B	*SE*	*z*	*p*
Intercept	-0.660	0.188	-3.503	<.001
Gesture Condition- Manner	0.912	0.253	3.610	<.001
Gesture Condition – No gesture	0.237	0.263	0.901	.368

Note, for the gesture manipulation, the end state gesture condition was taken as the reference group and the other gesture conditions were contrasted to this.

.

The model shows the same pattern of results as in the main analysis in Chapter 4. Specifically, the model shows that there was a significant effect of being in the manner gesture condition as compared to the end state gesture condition, such that children in the manner gesture condition selected the same-manner videos more often. Further, the model also showed that there was no effect of being in the no gesture condition as compared to the end state gesture condition, such that the selected the same manner video equally often as each other.

In order to examine the effect of gesture between the no gesture and the manner gesture conditions the model was rerun using the manner gesture condition as the reference group (Model 2); contrasts were made between this group and the others. Table 4.2 reports the parameters of this model.

Table 2

Fixed effects of Model 2 (fixed effect of gesture condition)

	B	*SE*	*z*	*p*
Intercept	0.251	0.168	1.495	.135
Gesture Condition- End State gesture	-0.912	0.253	-3.610	<.001
Gesture Condition – No gesture	-0.674	0.249	-2.708	.001

Note, for the gesture manipulation, the manner gesture condition was taken as the reference group and the other gesture conditions were contrasted to this.

As in the main analysis in Chapter 4, the model showed there was a significant effect of being in the no gesture condition as compared to the manner gesture condition, such that children in the manner gesture condition selected same manner videos more often. Similarly, there was a main effect of gesture between the manner gesture group and the end state gesture group.

Finally, without the data from the multilingual children, children who saw manner gestures did not differ from chance (0.5), whereas the other two groups did (end state gesture group: t (29) = -3.581, p=.001; no gesture group: t (29) = -2.223, p=.034).

Consistency across stimuli

We investigated how consistent the results were across stimulus items. First we considered consistency across the ten manners and then across the ten end states. For each comparison, we looked at the performance of the three gesture groups when each of the ten manners/ end states were used as the training video.

Consistency across manners

If we look at the pattern for all the gesture groups for the ten manners shown in the video stimuli, we see that the manner gesture group selected the same manner video at test more often than either of the other gesture groups for 8/10 manners. The end state gesture group only once selected more same manner videos that the manner gesture group. For seven of the manners, the no gesture group selected more same manner videos than the end state gesture group. See Figure 1 for the descriptive results.

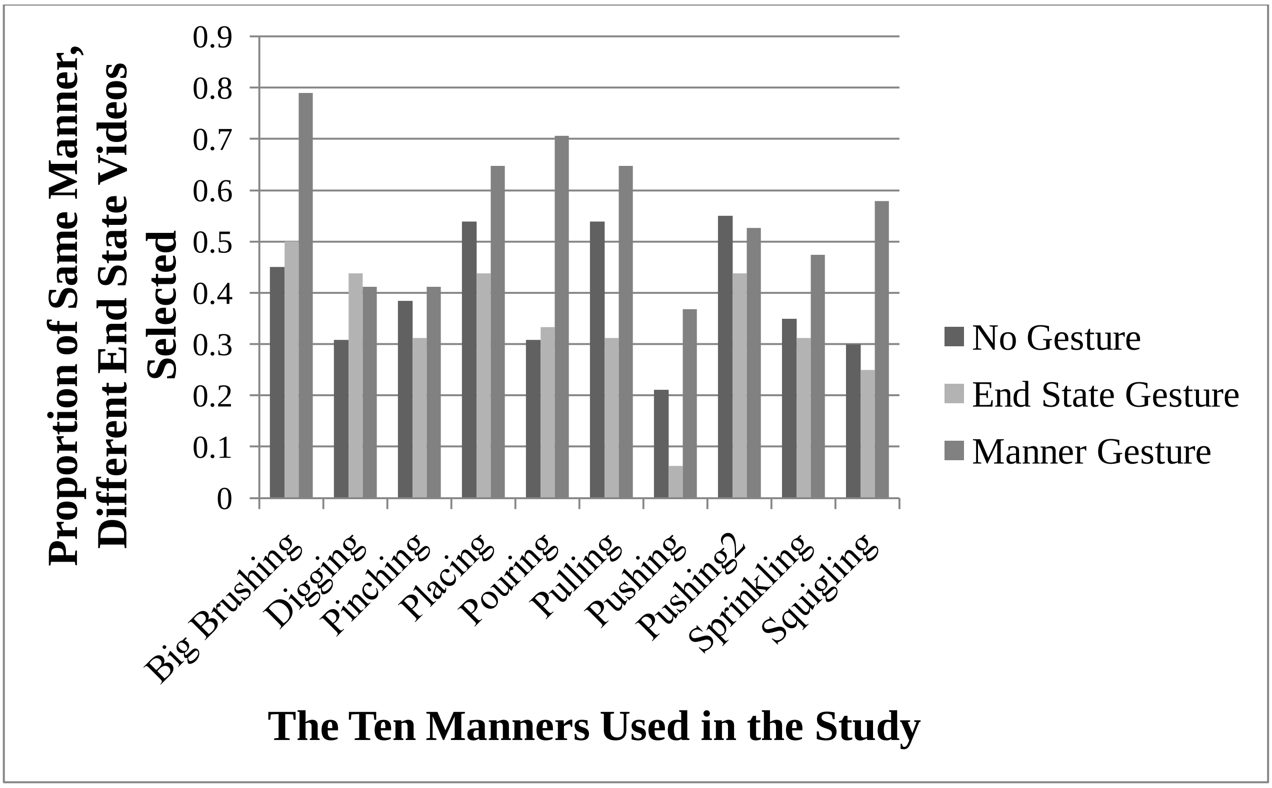


Figure 1. The proportion of trials in which the same manner videos were selected (i.e., generalization based on manner) by the three gesture groups for the ten manners used in the study.

This pattern shows that across the ten manners, the results mimic those found in the main results. Specifically, for 80% of the manners, children who saw manner gestures were generally more likely than the other two gesture groups to select the same manner video at test.

Consistency across end states

If we look at the pattern for all the gesture groups across all ten end states, we see that the manner gesture group selected the same-manner video more often than the other two gesture groups for 8/10 of the manners, and the end state gesture group selected the same-manner video less often than the manner gesture group for 9/10 of the end states. For 5/10 end states, the end state gesture group selected the same manner video less than either of the other two gesture groups. See Figure 2 for the descriptive results.

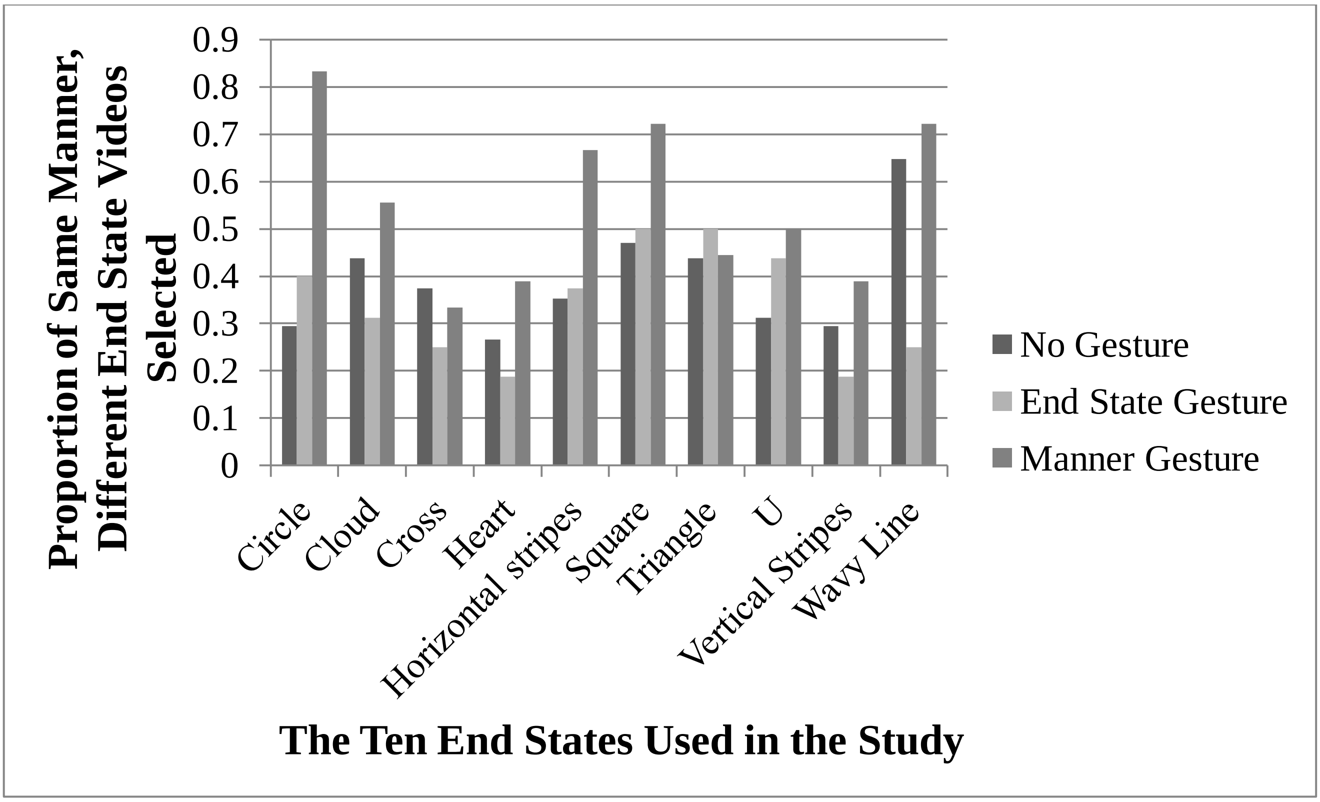


Figure 2. The proportion of trials in which the same manner, different end state video (i.e., generalisation based on manner) was selected for the three gesture groups across the ten end states.

This pattern shows again mimics the main results, such that for 90% of the end states, children who saw end state gestures were less likely than children who saw manner gestures to select the same manner video at test.

The results also reflect the lack of difference in performance between the end state gesture and the no gesture groups, as they each selected a smaller number of same manner videos at test than each other for half of the end states.

Conclusion

Overall, the descriptive patterns obtained are similar to the ones found in the main analysis, such that there is little difference between the end state gesture and no gesture group (particularly when looking across end states), but there is a consistent difference between the manner gesture group and the other two groups, such that children who saw manner gestures selected the same manner video more frequently. This pattern is fairly consistent across stimuli, and it was not the case that a small number of items drove the effect.

APPENDIX 8

Details of the reliability analysis for Chapter 6.

A second observer coded all of the data. For gesture type, the two coders agreed on 86% of the gestures (*Kappa*=.814, *N*= 348, *p*<.001). The handedness agreement (right bias, left bias or equal dominance) between the two coders were as follows: for pointing gestures, 87% agreement (*Kappa* =.778, *N*=89, *p*<.001); handling toys, 84% agreement (*Kappa* =.749, *N*= 154, *p*<.001). The nature of most disagreements were when the primary coder rated an action as equal dominant while the other coder gave a hand bias. The primary coder was therefore more conservative. Next actions in which both coders gave the action a handedness bias were investigated. For pointing gestures they agreed for 96% of gestures (*Kappa*= .923, *N*= 79, *p*<.001) and for handling trials they agreed on handedness on 100% of trials (*Kappa* = 1.00, *N*= 114, *p*<.001). The primary coder's data was used in the analysis. Note that both coders rated the videos blind in terms of language scores.

APPENDIX 9

Details of excluded children from the experiment in Chapter 8.

Twenty-nine children were excluded from the analysis for various reasons. Ten of these children were removed because they showed a side bias (only selecting videos in one location). Three other children were removed as they were very distracted during the experiment and only finished 1, 2 or 3 out of 7 trials each. One child was removed as she used the incorrect hand on all but one of the trials in the experiment. Seven children with known or suspected speech and/or language impairments were excluded. This is because some evidence suggests that atypical language development, such as persistent specific language impairment, is thought be associated with atypical language laterality patterns[4] (e.g. Whitehouse & Bishop, 2008; de Guiber, Maumet, Jannin, Ferre, Treguier, Barillot et al., 2011). Finally, eight of the remaining children were strongly left-handed in object manipulation (they used their left hand as the dominant hand in both manual handedness tasks). These children were removed from the analysis as left-handed individuals are more likely to have a less typical language laterality pattern (e.g. Knecht, Drager, Deppe, Bobe, Lohmann, Floel et al., 2000). Therefore the final data set came from 131 children: 32 in the memory task- right-hand condition, 30 in the memory task- left-hand condition, 33 in the verb learning task- right-hand condition and 36 in the verb learning task- left-hand condition.

Five additional children were excluded after the practice trials, and did not complete the main study, as they could not retain or obey the rule of only using one hand to respond.

---

[4] It should be noted that the literature on whether speech and language impairments are associated with atypical language laterality patterns is not consistent. For example, in a group of healthy participants, language lateralisation patterns were not associated with linguistic abilities (Knecht, Drager, Floel, Lohmann, Breitenstein, Deppe et al., 2001).

APPENDIX 10

The stimuli used in the study described in Chapter 8 (taken from Mumford & Kita, 2010).

Group	Action 1	Action 2
A	*Shuffling*: The actor moves by small shuffling movements, with the feet close together	*Flicking*: The actor makes small jumps with the legs extended straight in front
B	*Skating*: The actor slides each foot out the side one at a time with the foot flexed.	*Crossing*: The actor's feet step across the body's midline, with knees high and walking on the balls of the feet.
C	*Jumping*: The actor has a long stance (with one foot in front of the other) then jumps and lands with the opposite foot in front.	*Dropping*: The actor drops and rises by bending the knees whilst walking forwards. The back remains vertical.
D	*Wobbling*: The actor rotates their whole torso in large circles around the waist, while walking forwards.	*Marching*: The actor marches slowly using straight legs.

E	*Twisting*: The actor rotates their torso around the waist towards the left then right side, while walking forwards. The back is kept horizontal.	*Trotting*: The actor has one knee is bent at a right angle to the body, this leg is then changed by using a small jumping action.
F	*Bowing*: The actor bends forwards from the waist then returns to vertical, while walking forwards.	*Creeping*: The actor using small, careful steps on the balls of the feet.
G	*Scurrying*: The actor makes small, quick motions on the balls of the feet.	*Stomping*: The actor makes slow, heavy movement with the legs wide.