Pointing the Way Forward: The Role of Gesture in Preschoolers' and Adults' Communication and Comprehension of Route Direction Information

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This thesis is submitted for the degree of Doctor of Philosophy

August 25th 2017

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Abstract

Speakers and listeners use gesture as an integral part of the thinking and communication process. Research has shown that producing gestures enhances spatial task performance for young preschool-aged children and adults, although the relationship between gesture and speech content needs clarification. It is not yet clear whether gesture that repeats speech content is useful, or only gesture that is unique. Further, while it is known that producing gestures accompanying speech enhances memory and speech production for speakers, it is not yet known whether gestures benefit listeners' comprehension and subsequent recall of spatial information. Finally, it is not known whether particular types of gestures accompanying spatial messages are more beneficial to listeners' recall than others. The aim of this thesis was to clarify the role of gesture on spatial route communication and recall across development. Across four studies, this thesis investigated (1) the information relationship between the gestures and speech phrases produced by three- to five- year old children and adults when conveying spatial route information; (2) whether gestures accompanying route directions enhance listeners' recall during development; and (3) whether gestures accompanying route directions enhance adult listeners' recall. Findings were threefold. First, there were important developmental differences in the production of gestures accompanying route direction information, suggesting spatial conceptualisation changes as language and cognition develop. Second, gestures accompanying spoken route directions enhanced both verbal recall and physical route navigation during early childhood. Finally, gestures accompanying spoken route directions enhanced verbal recall for adult listeners when the spoken message was incomplete. However, the benefit of gestures accompanying route directions for adult listeners may depend on the method of recall, with poorer physical route navigation by listeners presented with gestures accompanying route information. Thus, this thesis showed that gestures are an integral part of the spatial communication environment

for both speakers and listeners, facilitating spatial information delivery and recall, and ultimately influencing spatial information application.

Statement of Candidature

I certify that the work in this thesis entitled “Pointing the Way Forward: The Role of Gesture in Preschoolers’ and Adults’ Communication and Comprehension of Route Direction Information” has not previously been submitted for a higher degree to any other university or institution other than Macquarie University.

I also certify that any sources of information used throughout the thesis are acknowledged, including any help or assistance that I have received in my work and preparation of this thesis.

The research presented in this thesis was reviewed and approved by the Macquarie University Human Research Ethics Committee, reference numbers: 5201300337, and 5201500835

Elizabeth Austin (41778014)

25th August 2017

Acknowledgments

I would like to take this opportunity to thank the Macquarie University Department of Psychology, in particular the staff members whose teaching developed my interest in psychology throughout my undergraduate degree, Honours, and now Ph.D. Special thanks to Avril Moss, Chandera Rajah, Eugene Chekaluk, Cathy McMahon, Kevin Brooks, Mike Jones, and Alan Taylor, for your support, encouragement and advocacy.

Naomi, when I was allocated a supervisor at the beginning of Honours I had no idea how lucky I would be, and five years working with you has confirmed that you are exactly the type of advisor anyone could hope for. Among other things, you have taught me how to conduct and analyse research, how to write manuscripts (and revise them repeatedly…. Including the correct use of apostrophes), and how to present my research. Although I appreciate that guidance, here are the reasons I really value you as a supervisor: you have given me the freedom to develop my own identity as a researcher by allowing me to come up with my own ideas for experiments and then working with me to make them better, beginning with my Honours project. Your encouragement, understanding, support, guidance and patience while I developed my research, teaching and presentation skills has shaped how I think and share ideas, as well as me for the better. Finally, supervisors invest a lot in their students and care about their research productivity, but you have cared about my quality of life outside of the research bubble and have not only been my mentor, but also a great friend. You have taught me that patience, deliberation and stoicism are necessary for the research process and that statistics is often the most satisfying (and fun) part of the research process. Thank you.

Special thanks go to Penny Van Bergen for agreeing to join my super-awesome-supervisory team. I know you help many students besides myself, but it means a lot to me that you were part of my journey and I don’t know how to thank you enough. Your constant positive encouragement, support and problem-solving brilliance made a massive difference. Thank you for your patience while I worked on developing my skills as a writer and reviser, your feedback has shaped the way I think and communicate my work immeasurably. Thank you also, for caring about my quality of life outside of the research bubble and being a friend. You have gone above and beyond. Special thanks also go to Amanda Barnier, I cannot fully express my appreciation for the guidance and support you have shown me during my Ph.D. journey. Your support has opened numerous doors and opportunities for me that I would never have had.

I am blessed to have the support and friendship of my fellow candidates walking beside me on the bumpy road. In particular, the Think Tank – Ash, Beck, Jo, Maddie, Trish, Tuki, and Wes – for walking with me during the research journey. I already miss having you around on a daily basis. Humungous thank you to Alissa, Vana, Fabiola and Nikki for your friendship and for the many fantastic conversations that have helped make stressful periods of this process more bearable. I look forward to many more fantastic conversations in the future.

Julie and Peter Austin, I could not hope to list the ways in which you have been incredible parents and have helped me get to this point in my educational career. Thank you for the countless debriefs over the past 4 years in which you have helped keep things in perspective, and thank you for your constant encouragement, love and support, without which I could not have completed this thesis with my intestines intact. Aaron and Jesse, you are incredible men and I feel blessed to have you as my brothers. Thank you for your friendship, love and support before, during, and after my time at university. To all four of you - you have had confidence in my ability to complete this dissertation (and everything else I have attempted to do in the past) regardless of my recurrent periods of self-doubt, and that confidence has been more important than I can express in words.

Thesis by Publication

This thesis has been prepared in the Macquarie University ‘thesis by publication’ format. Chapters two through four have been written and prepared as independent publications. Given this, there is some overlap in the literature cited and some unavoidable repetition across chapters. For ease of reading, this repetition has been minimised as much as possible. The formatting of the chapters generally conforms to the Publication Manual of the APA, 6th edition, although tables and figures are inserted within the manuscripts, and chapters are cross-referenced to assist with the readability of the thesis. Before each manuscript, there is a brief introductory section that provides a rationale for the study in the context of the thesis, and which also details the individual contributions of myself and co-authors.

Chapter 1. Introduction

Thesis Overview

Children and adults use verbal skills (i.e., language) and non-verbal techniques (i.e., gestures) to communicate and comprehend spatial information. Gestures, defined as any action used to communicate with another individual, may involve speakers' hands, arms, fingers, facial features or even the entire body (Kendon, 1972, 2004; McNeill, 1992). The empirically demonstrated benefit of gestures for enhancing performance on a range of tasks for children and adults has generated much interest in the role of gesture in communication. While these associations have consistent empirical support for non-spatial tasks (e.g., Cohen & Otterbein, 1992; Feyereisen, 2006; Igualada, Esteve-Gibert, & Prieto, 2017; Morford & Goldin-Meadow, 1992; So, Sim Chen-Hui, & Low Wei-Shan, 2012; Thompson, Driscoll, & Markson, 1998), there is a need for research examining the role of gesture for spatial tasks, as well as the function and mechanisms through which gesture might act for both speakers (producers) and listeners (observers). Furthermore, developmental differences in the production and processing of information conveyed through the two modalities raises questions about age-related changes in spatial conceptualisation, and relatedly, whether these differences reflect changes in the cognitive processing of spatial information. The overall aim of this thesis, therefore, is to address questions about the function and underlying mechanisms of gesture for both speakers and listeners during spatial communication, and in so doing, to help further clarify the role of gesture in communication for both speakers and listeners.

According to embodied cognition literature, speakers externalise thought processes through the production of gesture (Hostetter & Alibali, 2008; Wilson, 2002). By re-representing actions, gestures reflect speakers' internal representations and influence the communication environment for both speakers and listeners (Hostetter & Alibali, 2008; Tversky, 2011; Wilson, 2002). As re-represented actions, gestures are particularly good at conveying actions. Consequently, gestures may be particularly beneficial for speakers and listeners during spatial communication. However, the meaningful way speakers use gesture in conjunction with speech phrases requires further examination, with existing literature documenting the morphological relationship between adults' gesture and spoken referents. Examining the meaningful relationship between types of gesture and types of speech in both children and adults will enhance our understanding of the cognitive processes involved in spatial communication. Furthermore, the ways in which gestures influence listener task performance requires further clarification, with existing research primarily focusing on the effects of speakers' gesture production during task performance. Examining the influence of speakers' gesture on listeners' task performance during crucial language and cognitive development years will enhance our understanding of the cognitive processes involved in processing and conveying information. Importantly, research needs to consider the potential impact of speakers' gestures for listeners at different points in development, on specific tasks such as spatial communication, in order to better understand what role gesture plays in spatial cognition for both speakers and listeners.

This thesis will examine both the communication of spatial information through speech and gesture, along with the impact of spatial information conveyed through speech and gesture on listeners' task performance. Specifically, it will characterise the types of gestures young children and adults produce when conveying spatial information, as well as the relationship between type of gesture and type of speech phrase. Due to gesture's theorised role in facilitating speakers' cognitive processes, developmental differences between preschoolers and adults will be a particular focus. Importantly, existing literature has not yet clarified whether developmental differences in cognitive capacities (e.g., language, spatial ability, memory) impact how gesture is used in the communication of spatial information. In addition, this thesis will investigate whether spatial information conveyed through speech and gesture enhances recall of spatial information. In order to understand whether different types of gesture impact how listeners use gesture in the communication of spatial information, the effect of different types of gesture accompanying spatial information will be examined.

To address questions about the role of gesture in communication for both speakers and listeners, the thesis contains a review of the literature, four distinct empirical works presented across three chapters, and a concluding chapter in which the results from all four empirical works are discussed. The review of the gesture literature will set the context for the work that follows. Gesture classification (including the distinction between redundant and non-redundant gestures) and theory explaining the production of gestures will be outlined, as well as the developmental trajectory of gesture production and the function of gesture production for speakers. To provide context, spatial tasks will be defined and the function of gestures for speakers will be applied to the communication of spatial information. In addition, the role of gestures in communicating spatial information to listeners, as well as the function of gesture will be presented. Finally, the chapter will end with the overarching aims of the thesis. It will outline the work that will be presented in each following chapter and establish how, together, the chapters add to the understanding of how and why gestures are produced in spatial communication.

The Definition and Origin of Gesture Production

Communication is both a bridge between the self and others and a chasm where meaning can be lost. When we communicate, we share or make common our thoughts using a combination of verbal and nonverbal behaviours (Clark, 1996; McNeill, 1992, 2005; Tversky, 2011). Nonverbal components of communication (including hand movement, facial expression, and eye gaze) synchronise with verbal components of communication (including language, tone and pitch of voice) to convey knowledge and ideas, thus embodying thought processes (Cartmill & Goldin-Meadow, 2016; Clark, 1996; Tversky, 2011). Children produce visual forms of communication such as gesture throughout the language learning process, evolving together to form a single integrated communication system (McNeill, 1992). The combination of verbal and nonverbal components in communication provides individuals with an adaptable scaffold for knowledge acquisition, particularly during the developmental years (Goldin-Meadow, 2016).

Linked by production and perception, language and gesture differ in their expression of meaning and structure, interacting to facilitate effective communication (Goldin-Meadow, 2016; Wagner, Malisz, & Kopp, 2014). Language rules regarding syntax and grammar structure the formulation and production of speech, whereas composition rules do not apply to gestures. As a result, gestures can directly convey information through their resemblance to aspects of speech content (Clark, 1996; Tversky, 2011). Capturing select characteristics of the world, nonverbal communication often conveys information typically perceived as not essential for the task at hand (Tversky, 2011). However, these non-verbal signals can express a lot of information about knowledge, attitudes, and our internal experience. Unfiltered by formal production rules, gestures allow us to directly convey our thoughts and provide researchers with a window into the cognitive processes underlying language and thinking, particularly when speakers' language skills are limited (Church, Kelly, & Wakefield, 2016).

There has been interest in the relationship between speech and gesture from the speech-gesture community, particularly regarding the primary functional interaction between gesture and speech in aiding communication, facilitating speech production and conveying meaning (Wagner et al., 2014). For both speakers and listeners, the interaction of a message through two modalities (verbal: speech and visual: gesture) has significant cognitive implications. Examining visual communication in relation to verbal communication can enrich our understanding of the underlying thought processes involved. The link between gestures accompanying speech and mental imagery has provided researchers with a means for assessing underlying cognitive processes. Gestures offer a way for researchers to access thought processes and to study cognition. Gestures, however, have been defined in many ways.

Types of Gesture

Gestures are largely unconscious movements that typically synchronise with speech in both time and meaning (McNeill, 1992; McNeill, Cassell, & McCullough, 1994). While spontaneous gestures are not dictated by any formal rules, they are distinct from non-gestures (i.e., movements or actions involving objects which do not relate to speech content; e.g., stroking the hair), pantomime (i.e., interpretable action not accompanied by speech), sign language (e.g., American Sign Language, a linguistic system with established syntax and grammar), object manipulations (e.g., opening a box), and emblems (e.g., thumb and forefinger touching to symbolise “ok”; McNeill, 1992; McNeill et al., 1994). The multi-dimensional nature of gestures, the lack of conventional form and meaning, as well as the content relationship with speech, make gestures difficult to identify and compare (Church et al., 2016; Kendon, 1972).

Kendon (1972, 2004) outlined a continuum along which gestures can be classified reflecting their relation to speech. Kendon (2004) categorised gestures along the continuum according to the presence of speech and the gesture’s degree of idiosyncrasy. Gestures that can be understood independently of speech content and that have conventional form (i.e., sign language, emblems, and pantomimes) are at one end of the continuum. Produced intentionally by speakers, these gestures are composed of various lexical units and do not need the presence of speech to be understood. Spontaneous gestures, that is, movements produced in the presence of speech that have no conventional form are on the other end of the continuum (Kendon, 1972, 2004; McNeill, 1992). Linked semantically and temporally to the speech they accompany, spontaneous gestures can be further divided into imagistic (i.e., iconic, metaphoric) and non-imagistic (i.e., beat, deictic) categories (Kendon, 1972, 2004; McNeill, 1992).

Imagistic gestures are movements that can be interpreted as conveying the shape, movement or action of a referent referred to in speech (Kendon, 2004). Iconic gestures are classified by their close resemblance in form and manner to the semantic content of speech (McNeill, 1992). For example, enacting climbing, accompanying the phrase “we went up the tree” depicts in its manner of execution a feature referred to in speech, namely the way the tree was climbed. While the gesture omits other aspects (e.g., the identity of the character), it is classified as iconic because of its form / shape and upward trajectory. Metaphoric gestures are classified by their resemblance in form and/ or manner to abstract concepts, for which there is no physical referent (McNeill, 1992). For example, portraying the weighing of two objects simultaneously, accompanying an explanation about good and evil depicts in its manner of execution the concept referred to in speech, namely how judgments of good and evil depend on perspective. In both cases, the gesture conveys an image of something that could be a concrete action or object, however, it is the relation to speakers’ speech content that determines if the gesture is classified as iconic or metaphoric (Kendon, 2004).

Conversely, non-imagistic gestures do not convey an image but highlight aspects of speech or the rhythmic structure of speech (Kendon, 2004). Deictic gestures are pointing gestures, typically performed with the pointing finger, though any part of the body (e.g., chin) or object (e.g., pen) may be used (McNeill, 1992; 2005). The meaning of a deictic gesture depends on the referential value attached to the region indicated by the gesture (McNeill, 1992; 2005). For example, pointing to the left, accompanying the phrase “the tree is over there”, depicts in its form a feature referred to in speech: namely, the location of the tree. Beat gestures do not convey any apparent semantic meaning and are classified by their typically biphasic, small, low energy, rapid flicks of the fingers or hands, performed wherever the hands happened to be (McNeill, 1992; 2005).

The meaning of gesture depends on the words they accompany (Kendon, 1972, 2004; McNeill, 1992). Therefore, gestures can be defined by the degree to which they convey information not found in speech content (Cartmill & Goldin-Meadow, 2016). Redundant gestures replicate the semantic meaning of the words they accompany (McNeill et al., 1994). For example, “the grass area is flat” accompanied by a gesture indicating a flat surface, conveys through both speech and gesture that there is a flat surface. Conversely, non-redundant gestures supplement speech, conveying information about the scene that is left out of speech (McNeill, 1992; McNeill et al., 1994). For example, “go out the door” accompanied by a gesture indicating two sliding doors, conveys information beyond speech content, namely how the doors referred to in speech operate. The semantic relationship between speech and gesture often falls somewhere in between redundant and non-redundant, with gestures reflecting spoken information while also conveying some additional details (e.g., about size, shape, or location; Cartmill & Goldin-Meadow, 2016). The redundant / non-redundant distinction does not apply to beat gestures, however, due to beat gestures’ lack of apparent semantic relationship with speech. Beat gestures may indicate other communicative aspects such as emphasis, thereby functioning as a discourse marker (Allen, 2003; McNeill, 1992, 2005).

While speech and gesture represent meaning in different ways, they integrate in both time and meaning to form a single communication system (Goldin-Meadow, 2016). Speech allows us to covey both concrete and abstract thoughts and meanings (Tversky, 2011). Conversely, spontaneous gestures require speech to be understood and can convey information consistent with and / or beyond the spoken message (Kendon, 1972, 2004; McNeill, 1992; Tversky, 2011). Due to their form and relation to speech, gestures are thought to reflect aspects of an individual's mental representations during the thinking and speaking process (Church et al., 2016). This link between speech, spontaneous gesture and mental imagery has provided researchers with a means for understanding how gestures arise from mental processes (Hostetter & Alibali, 2008).

The Origin of Gesture Production

Embodied cognition is the idea that perceptual and motor processes play a central role in shaping thought processes (Wilson, 2002). According to embodied cognition, our physical interactions with the world ground cognitive processes in the environment (Wilson, 2002). The embodied cognition approach can inform thinking about how gestures arise and how they represent speakers' active thoughts during thinking and speaking (Hostetter & Alibali, 2008). When performing tasks situated in the immediate environment, we can use the body (i.e., gestures) to offload information or cognitive work onto the environment (Wilson, 2002). In this way, the mind and body interact in a real world situation. Similarly, when performing mental tasks where referents are distant in time and space or are imaginary, we can use the body (i.e., gestures) as symbolic offloading to assist in the mental representation and manipulation of objects and ideas that are not present (Wilson, 2002). Whether the task is situated in the immediate physical world, or in the mind, we can use our body to facilitate thought processes.

Based on embodied cognition literature, the Gesture as Simulated Action (GSA) framework offers an account of how gestures make embodiment visible (Hostetter & Alibali, 2008). The GSA framework suggests that mental processes which simulate action (i.e., mental representations of action) give rise to spontaneous gesture production (Hostetter & Alibali, 2008). That is, mentally simulating an action activates premotor action states and through spreading activation of motor areas, results in an overt gesture being produced (Hostetter & Alibali, 2008). Activation of motor areas does not always lead to overt gesture production, with speakers sometimes producing speech unaccompanied by spontaneous gestures (Hostetter & Alibali, 2008).

According to GSA, the production of a gesture depends on the strength of the activation, the individual's gesture threshold and the simultaneous engagement of the motor system for speaking (Hostetter & Alibali, 2008). The strength of premotor and motor area activation is determined by mental simulation characteristics, with greater activation occurring when simulations involve action, visual or motor imagery and concrete events and objects (Hostetter & Alibali, 2008). For overt gesture production, the strength of the activation must be greater than the gesture threshold for the activation to spread from premotor to motor areas (Hostetter & Alibali, 2008). The gesture threshold varies and depends on the speaker's neural connections, experiences, current level of cognitive effort and the communication environment (Hostetter & Alibali, 2008). GSA explains how some gestures come to be produced, but it does not necessarily help us understand what gestures do for speakers who produce them or for their listeners (Novack & Goldin-Meadow, 2015).

Thinking and communicating take place within the context of the environment (Wilson, 2002). As a result, the production of gesture and its function for speakers needs to be understood in that context (Wilson, 2002). Our ability to process, store, and convey information ultimately depends on our cognitive characteristics (Just & Carpenter, 1992). Embodied cognition theory suggests that we use the environment, through the production of gestures, to hold and / or manipulate information in order to overcome the limitations in our ability to simultaneously process information (e.g., attention and working memory; Macken & Ginns, 2014; Wesp et al., 2001; Wilson, 2002). In this way, externalising or embodying mental representations of our thoughts through the production of gestures during thinking and communication can extend the limits of our cognitive characteristics, and thereby further support the thinking process (Wilson, 2002). The next section presents empirical evidence for the role of gesture in communication for speakers and listeners.

The Role of Gesture in Communication for Speakers and Listeners

Speakers Produce Gesture When Communicating Information

The development of gesture production. The development of gesture plays an important role in the formation and communication of cognitive processes. Children use gestures to communicate before they can speak, typically producing their first gestures between 9 and 12 months of age (Bates, 1976; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979). All children use gesture to communicate but the relationship between gestures and words varies in relation to developmental stage (Capirci, Contaldo, Caselli, & Volterra, 2005). The first intentional gestures children produce appear at around 10 months of age and involve infants pointing, showing or giving objects (Capone & McGregor, 2004; Colonnesi, Stams, Koster & Noom, 2010; Esteve-Gibert & Prieto, 2014; Iverson & Goldin-Meadow, 2005). Considered a key joint attention behaviour, these deictic gestures help to focus others’ attention during social communication. Producing pointing gestures is an important milestone in children’s linguistic and social development, with a large body of research suggesting that the comprehension and production of deictic gestures is related to language development (Colonnesi et al., 2010; Esteve-Gibert & Prieto, 2014).

Gestures continue to account for a large portion of communication between ages 12 to 18 months as children transition from gesture-only to single word utterances, to gesture-plus-word combinations before producing their first two-word sentence (Capirci et al., 2005; Iverson & Goldin-Meadow, 2005). For example, Iverson and Goldin-Meadow (2005) observed 10 children during play with a caregiver and during mealtime from the age of 10 months to 24 months. Between the ages 10-14 months, most children primarily referred to objects through gesture only, changing to speech only by 24 months of age (Iverson & Goldin-Meadow, 2005). Children combined single gestures with single words, both redundant (point at a bird while saying bird) and non-redundant (point at a sleeping bird while saying nap), before producing two-word utterances (Iverson & Goldin-Meadow, 2005).

The ability to combine two different semantic elements in early gesture-speech combinations (i.e., supplementary gesture plus word combination) predicts and precedes the emergence of two-word combinations with sentence-like meanings (Iverson & Goldin-Meadow, 2005; Stanfield, Williamson, & Özçalışkan, 2014). When interacting with a caregiver, children produced more gesture-speech combinations over time (i.e., 14 months to 24 months), particularly supplementary gesture-speech combinations (e.g., “eat” + point at muffin; Özçalışkan & Goldin-Meadow, 2005). In this way, gestures provide children with a means to refer to objects which they do not yet have the words for and convey increasingly complex ideas (Iverson & Goldin-Meadow, 2005; Özçalışkan & Goldin-Meadow, 2005). Children’s production of gesture during interactions elicits from the caregiver nouns and verbs not yet in their repertoire, providing a way for new words to enter children's communicative repertoire (Iverson & Goldin-Meadow, 2005; Özçalışkan & Goldin-Meadow, 2005). The most productive type of communication used by children involves combinations of pointing and representational words (deictic gestures account for 80% of children's gesture repertoire by 12 months of age), with iconic gestures developing slightly later (Capirci et al., 2005; Capone & McGregor, 2004; Stanfield et al., 2014).

Combining words with gesture in a meaningful way is a significant developmental step. However, there are some inconsistencies in the literature about the exact age at which iconic gestures are well understood (Özçalışkan & Goldin-Meadow, 2005). At 2 years of age, children are capable of producing spontaneous iconic gestures when explaining how to perform actions (Behne, Carpenter, & Tomasello, 2014; Capone & McGregor, 2004). Some evidence suggests, however, that it is not until 3 years of age that children develop the capacity to extract the meaning of iconic gestures accompanying a sentence (Stanfield et al., 2014). The difference in developmental trajectory of iconic and deictic gestures suggests that the production and comprehension of iconic gestures is more complex than deictic gestures. Unlike deictic and iconic gestures, little is known about the developmental trajectory of beat and metaphoric gestures which typically emerge later in development (i.e., the early school years; Goldin-Meadow, 1998; Guidetti & Nicoladis, 2008). Importantly, gesture enables young children to communicate multiple pieces of information, meanings, and complex ideas before they have the vocabulary to do so.

Gesture production facilitates the development and communication of cognitive changes during early childhood. As word learning progresses, the communicative repertoire shifts from primarily gesture production to verbal communication by 20 months, with children beginning to produce two-word utterances at around 17-22 months (Bates et al., 1988; Capirci et al., 2005; Capone & McGregor, 2004). Sensorimotor experiences ground language learning in the physical world through the associations made between movements of the body (gestures) and the context of the spoken word (Yu, Ballard, & Aslin, 2005). As such, nouns are easier to grasp than verbs, as nouns are more imaginable / observable than verbs, whereas verbs reflect complex concepts such as relations or actions, which are harder to perceive (Yu et al., 2005). Consistent with this difference, children's early word meanings are perceptual (based on the concrete environment) and not functional (based on abstract relatedness), with children learning nouns (e.g., bed, cat) faster than verbs (e.g., painting; Gentner, 1978; Tomasello, Akhtar, Dodson, & Rekau, 1997). While children differ in word learning abilities and language background, language and gesture proficiency increase steadily from age 3 – 4 years (Astington & Jenkins, 1999). By ages 3 – 5 (i.e., preschool age) language and gesture are integrated (i.e., produced simultaneously) and readily used by children (Cameron & Xu, 2011). As demonstrated by the above studies, gestures play a fundamental role in language development and communication (Bates et al., 1988; Cameron & Xu, 2011; Capirci et al., 2005; Capone & McGregor, 2004; Yu et al., 2005). Therefore, examining the gestures children produce during early childhood can enhance our understanding of the knowledge and conceptual changes which occur during cognitive development.

Language and gesture play a fundamental role in the development and communication of important cognitive changes which occur during the preschool years (i.e., 3-5 years of age), for example, theory of mind (Mutter, Alcorn, & Welsh, 2006; Wellman, Cross, & Watson, 2001; Keenan, Olson, & Marini, 1998; Wimmer & Perner, 1983). Theory of mind is the understanding that others have mental states (beliefs, desires, intentions) separate to the self, involving reasoning about others, social awareness, joint attention and anticipation of others' behaviour (Astington & Jenkins, 1999; Davis & Pratt, 1995; Hollebrandse, van Hout, & Hendriks, 2014). Representational theory of mind develops towards the end of the preschool years (i.e., age 5) and involves the ability to attribute false belief to the self and others and the ability to distinguish between appearance and reality (Astington & Jenkins, 1999). While children need language to display their theory of mind skills in false belief tasks, language plays a fundamental role in the development of theory of mind (Astington & Jenkins, 1999). Understanding about the intentions of some pointing gestures at 12 months of age can predict later understanding about the mental states behind others' actions (Colonnesi, Rieffe, Koops, & Perucchini, 2008). The existing literature presented above demonstrates that children's gesture production facilitates language acquisition and communication and provides listeners with valuable insight into cognitive changes during development (Bates et al., 1988; Capirci et al., 2005; Capone & McGregor, 2004; Yu et al., 2005). Examining the gestures adults produce can enhance our understanding of the role gesture plays in communication and cognition throughout the lifespan.

Gesture production continues throughout the lifespan. Despite increased vocabulary and cognitive abilities with age, individuals continue to integrate speech and gesture during thinking and communication throughout the lifespan. Existing research demonstrates that gesture plays an important role in facilitating communication for adult speakers (Alibali, Heath, & Myers, 2001; Chu & Hagoort, 2014; Church, Kelly, & Holcombe, 2014). Investigating the integrated relationship between speech and gesture during communication, Church et al. (2014) asked adults to perform tasks which elicited descriptions about actions on objects (i.e., speech and action combinations), and descriptions about how to act on objects (i.e., speech and gesture combinations). The synchronisation of speech and gesture during descriptions was greater than the synchronisation of speech and action during descriptions. The greater synchronisation of gesture with speech than action with speech suggests that speech and gesture work together for the purposes of communication (Church et al., 2014). Furthermore, there is evidence that disrupting gesture disrupts spoken communication (Chu & Hagoort, 2014). Chu and Hagoort (2014) asked adults to point to and / or name a light that had lit up. Using virtual reality, the visual feedback gesture provided to speakers was manipulated by delaying or disrupting the gesture. When receiving delayed visual feedback, adults prolonged their gesture production and delayed their speech onset time. The more the apex of a gesture was delayed, the more speech onset was delayed. Taken together, the synchronisation of speech and gesture production suggests that speech and gesture interact with each other during communication (Chu & Hagoort, 2014). Despite the increased cognitive capacity and abilities that come with age, gestures continue to play a role in the communication process for speakers, as evidenced by the disruption to speech when interruptions to gestures occur.

Beyond gestures facilitating the speech production process, there is evidence that gesture production facilitates speakers' communication of meaning (Alibali et al., 2001). To examine the influence of listener visibility on speakers' speech (i.e., type of content and rate) and gesture (i.e.,type of gesture and rate) production, Alibali et al. (2001) asked adults to narrate events from a cartoon to a listener. Listeners were asked to retell the story to the experimenter, who would be either face-to-face or behind a screen. Adults produced more imagistic gestures when the experimenter was visible than when the experimenter was behind a screen. Across speakers, the production of beat gesture was inconsistent, with some speakers producing more beats when the experimenter was visible, and other speakers producing more when the experimenter was not visible. Speakers' greater production of imagistic gesture in the presence of a listener suggests that gestures facilitate speakers' communication of meaning (Alibali et al., 2001). While this increase in production does not address whether gestures are in fact communicative or intentional, differences in gesture production depending on listener visibility implies speakers' gesture production plays an important role in facilitating communication for speakers (Alibali et al., 2001).

Spontaneous gestures may be an intentional aspect of social communication, with speakers adjusting their gesture production according to the perceived relevance to the audience. Kelly, Byrne, and Holler (2011) asked adults to read about items that were and were not useful in a wilderness survival scenario. Adults were then asked to explain (on camera) what they learned to one of two different audiences: either a group of college students in a dormitory orientation activity, or a group of students preparing for a rugged camping trip in the mountains. Adults produced more imagistic gestures when explaining the information to students going on a camping trip, than to students in a dormitory orientation. The greater production of gestures when explaining information to a relevant audience suggests that the degree of usefulness to the listeners influences speakers' production of gesture.

Gesture production facilitates cognitive processes during adulthood. Differences in cognitive abilities may also explain differences in adults' tendency to produce gesture. Gillespie, James, Federmeier, and Watson (2014) presented adults with 30 second clips of Tom and Jerry cartoons and asked them to describe the events in the cartoons (Gillespie et al., 2014). Adults with lower verbal working memory were more likely to produce gestures than adults with higher verbal working memory (Gillespie et al., 2014). The greater production of gesture by adults with lower verbal working memory suggests that gesture is produced by adults when task complexity challenges cognitive ability. Taken together, the presented findings suggest that integrated with speech, gesture plays an important role in facilitating communication for speakers. The development of gesture and the continued synchrony with speech into adulthood suggests that gestures play an important role in the formation and communication of cognitive processes throughout the lifespan. Speakers' development and continued production of gesture raises questions about the potential role of gesture in communication for listeners.

Listeners Benefit from the Presence of Gesture During Communication

Listeners integrate speakers' speech and gesture during development. During language development, listeners integrate speakers' speech and gesture to form associations between words and real-world experiences, thereby creating a mental representation of the spoken word or message (Esteve-Gibert, Prieto, & Liszkowski, 2017; Hostetter & Alibali, 2008; Yu et al., 2005). Word learning is challenging because words are arbitrary symbols, bearing no inherent relationship to their referents (e.g., nothing about the word "table" connects it to the object table; Quine, 1960; Rowe, Silverman, & Mullan, 2013). In contrast, gestures often reflect aspects of real-world objects and actions, containing information beyond the spoken message (Church, Garber, & Rogalski, 2007). Learning a word, therefore, involves using others' gestures to map a word to a conceptual representation (Yu et al., 2005). For listeners, gestures ground language in the physical environment and may facilitate language acquisition.

Along with word learning, speakers' gestures can facilitate listeners' acquisition of object manipulation knowledge. For example, Novack, Goldin-Meadow, and Woodward (2015) presented 2- and 3- year-old children with iconic gestures illustrating how to operate a novel toy for a particular action. Children produced more target actions after seeing an iconic gesture demonstration than no demonstration. However, 2-year-olds produced fewer target actions when presented with iconic demonstrations than an incomplete demonstration (e.g., watching someone attempt but fail the target action). Children's target action performance suggests that children understand that gestures convey task-relevant information, but that at 2 years of age, children are still acquiring the skills to successfully interpret these gestures. In a second study, Novack et al. (2015) compared 2-year-olds' performance following iconic gesture demonstrations with deictic gesture demonstrations. Iconic gesture demonstrations led to more target actions than did pointing gesture demonstrations. Children's target action performance suggests that at 2 years of age, children glean substantive information from iconic gestures about how to solve the problem beyond merely focusing their attention (Novack et al., 2015). Taken together, these studies suggest that during early childhood, children are able to use complex gestures (iconic) in task-related activities, but that learners' ability to correctly interpret the iconic form is fragile at this age. Importantly, gestures vary in communicative value, with some gestures benefiting listeners' task performance more than others.

For example, So et al. (2012), presented adults and children aged between 4 to 5 years with words accompanied by either iconic gestures, beat gestures, or no gestures, and asked them to recall the words without moving their hands. Both adults and children recalled more words accompanied by iconic gestures than no gestures. Interestingly, beat gestures aided recall for adults but not children. Greater recall of words accompanied by gesture suggests that for adults, both meaningful and non-meaningful gestures enhance memory, while children may not be sensitive to the emphasising aspect of beat gestures. Similarly, Macoun and Sweller (2016) presented preschoolers with a videotaped narrative accompanied by either iconic, deictic, or beat gestures, or no gesture. Of these gestures, half provided additional information beyond the presented speech (i.e., non-redundant), while the other half conveyed no additional information (i.e., redundant). Gestures facilitated children's comprehension of the narrative, with iconic and deictic gestures providing the greatest benefit to recall. Importantly, these differences were only found for gestures which conveyed additional information (Macoun & Sweller, 2016). Greater recall of narratives accompanied by gesture, particularly non-redundant gestures, suggests that children process and integrate information conveyed through speech and gesture. Overall, the literature suggests that during the language learning years, speakers' gestures play an important role in the comprehension, retention and subsequent recall of information. Furthermore, gestures which convey meaningful information beyond speech content enhance listeners' task performance to a greater extent than gestures which highlight aspects of speech at a time when language is still developing.

Listeners use the presence of gesture during communication throughout the lifespan. While research shows speakers' gestures enhance listeners' recall during early childhood, it also demonstrates that gestures play an important role in word and sentence retrieval for adult listeners (Thompson et al., 1998; Wu & Coulson, 2014). In a series of three experiments, Wu and Coulson (2014) presented adults with speech accompanied by gestures either matched or incongruent with speech content. Adult listeners were faster at classifying pictures as being related or unrelated when speakers' speech was accompanied by gestures that were consistent with speech content than by gestures that were inconsistent with speech content (Wu & Coulson, 2014). In addition, adults with greater visuospatial working memory capacity benefited more from gestures consistent with speech, suggesting that consistency between messages conveyed through speech and gesture facilitated comprehension, particularly for adults with greater memory capacity (Wu & Coulson, 2014). Similarly, Thompson et al., (1998) presented adults and children aged 9 and 10 years with meaningful and anomalous sentences accompanied either by no lip movement, lip movement, or a combination of iconic and metaphoric gestures. The additional cues provided by lip movement and gestures enhanced both adult and child recall of anomalous sentences but not meaningful sentences, suggesting that nonverbal cues benefit listeners when speech content is challenging. Taken together, these studies suggest that listeners benefit most from a speaker's gesture production when the spoken message is difficult to interpret. It is possible that the production of gesture plays a functional role in thinking and communication for speakers (Wesp, Hesse, Keutmann, & Wheaton, 2001; Wilson, 2002).

The Function of Gesture in Communication

The Function of Gesture in Communication for Speakers

Through form, position and movement, the same gesture may serve to reference and represent objects in speech, convey space and movement and facilitate cognition (Kok, Bergmann, Cienki, & Kopp, 2016). That is, gesture provides the cognitive system with a stable external physical and visual presence that can provide speakers with a means to think and communicate with (Pouw, de Nooijer, van Gog, Zwaan & Paas, 2014). Therefore, the embodiment of thought processes through gesture may serve two functions: (1) help speakers translate ideas into speech and / or (2) eliminate the need to translate ideas into speech at all (Hostetter & Alibali, 2007, 2008; Wilson, 2002).

As previously discussed in The Origin of Gesture Production section, gestures ground thought processes and communication in the physical environment, thereby allowing speakers to offload cognitive work (Cameron & Xu, 2011; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Just & Carpenter, 1992; Tversky, 2011; Wilson, 2002). At the same time, by reflecting speakers' mental representations, gestures also provide speakers with feedback on their own thought processes (Goldin-Meadow & Alibali, 2013; Madan & Singhal, 2012; Wilson, 2002). While gestures facilitate the management and allocation of mental resources, gestures may also enhance the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005).

Gestures may also play a functional role in the construction of phrases, and therefore further support the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing a gesture enacting flapping wings to indicate a bat, disambiguates it from a bat which might be accompanied by a gesture enacting swinging a cricket bat (Kidd & Holler, 2009). In this way, producing gesture provides individuals with a means to communicate ideas beyond existing cognitive limitations (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007, 2008; Madan & Singhal, 2012; Wilson, 2002). Importantly, gesture's role in facilitating thinking and the communication of meaning suggests that the embodiment of thought processes through gesture production may have dual, non-mutually exclusive functions for speakers. It is possible that speakers' externalisation of thought processes through gesture production also plays a functional role in communication for listeners.

The Function of Gesture in Communication for Listeners

As discussed in the previous section, embodying thought processes through the production of gestures benefits speakers' cognition and helps communicate information. However, gesture may also play a functional role in cognition and communication for listeners. The embodiment of speakers' thought processes through gesture production grounds language comprehension in the environment and suggests two pathways through which gesture may benefit listeners (Hostetter & Alibali, 2008). First, gestures scaffold speech comprehension by illustrating concepts, conveying additional information, and additional cues (Sauter, Uttal, Alman, Goldin-Meadow, & Levine, 2012). In this way, gestures accompanying spoken messages act to disambiguate the spoken message and are, therefore, particularly beneficial when speech is complex, ambiguous, or challenging to listeners' language skills (Alibali & Hostetter, 2010; McNeil, Alibali, & Evans, 2000; Morford & Goldin-Meadow, 1992). By clarifying spoken language, gestures indirectly reduce the information processing demands of language comprehension, thereby freeing cognitive resources for other processes such as memory (Cameron & Xu, 2011).

Second, embodied cognition theory suggests that processing information conveyed in speech and gesture activates the same perceptual and motor states involved in gesture production, thus generating a simulation of the speaker's message (Alibali & Hostetter, 2010). This activation reduces the information processing demands of memory by serving as an elaborate encoding strategy (Alibali & Hostetter, 2010; Just & Carpenter, 1992; Madan & Singhal, 2012). It is possible that the additional processing of visual and motor information provided by gestures reduces the information processing demands of verbal information thereby increasing cognitive resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992). For listeners, the potential beneficial effect of gesture at encoding on the reduction of processing demands and resulting increase in resources for task demands may be crucial during communication. Importantly, the presence of gesture during communication may be crucial in facilitating thinking and communication for both speakers and listeners. As gestures are a special type of action (representational action), then they may be particularly beneficial for tasks which require us to think and communicate about space (i.e., spatial tasks).

Spatial Tasks and the Role of Gesture in Spatial Communication for Speakers and Listeners

Defining Spatial Tasks and Spatial Knowledge Communication

Defining spatial tasks and the different scales of space. Spatial tasks tap into an individual's capacity to visualise space, understand spatial relations and imagine how objects will appear from another perspective (Chu & Kita, 2011). Spatial tasks can involve scales of space which range from small-scale (i.e., figure space) to large-scale (i.e., environmental; Chu & Kita, 2011). Small-scale spaces (e.g., a desktop, or a space within a room) are small enough to be seen from a single viewpoint (Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999). Typically based on a room or desktop environment, small-scale spatial tasks involve inspecting, imagining, or mentally transforming small objects (e.g., paper-pencil tasks, Tower of Hanoi; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). Laboratory based small-scale spatial tasks correspond to real-life tasks such as searching a desktop for keys, or arranging items within a room. In contrast, large-scale spaces such as buildings and cities are too large to be perceived from a single position (Mark et al., 1999; Nothegger, Winter, & Raubal, 2004). Rather, knowledge about large-scale spaces requires individuals to navigate through these environments: processing and integrating perceptual information (which changes with movement) over space and time, using memory and reasoning (Allen, 2000; Hegarty et al., 2006; Mark et al., 1999; Nothegger et al., 2004). Large-scale spatial tasks, such as navigating and following route directions, are carried out in larger spaces that surround the body. Consequently, navigation involves the integration of the sequence of views that change with one's movement through the environment (Hegarty et al., 2006).

Spatial knowledge acquisition and communication. Culture, language, and pragmatic skill can influence how individuals experience the environment. The way people experience space influences how they process perceptual information and, therefore, how they communicate about it. For example, when describing small-scale space, people describe objects in relation to each other from an external viewpoint, while they typically describe objects relative to an observer moving through the environment when describing large-scale space (Taylor & Tversky, 1996). Differences in spatial descriptions reflect differences in how individuals experience the environment, suggesting that the way people think about space (and the cognitive processes involved) depends on the scale of space involved. Furthermore, Hegarty et al. (2006) modeled individuals' performance on various spatial tasks at different scales of space and found a partial (though not total) dissociation between task performance at small and large scales of space. That is, although some overlap exists between small-scale and large-scale spatial task performance, performance on small-scale spatial tasks did not accurately reflect an individual's performance of spatial tasks at other scales of space (Hegarty et al., 2006). Importantly, these findings suggest that there is a difference in the cognitive processes involved in performing spatial tasks, depending on the scale of space involved. While understanding cognitive processes at all scales of space is important, understanding large-scale spatial knowledge communication (e.g., conveying route directions) is of particular interest as it requires speakers to integrate, process and convey information learnt from perceptual and motor experiences (Allen, 2000; Mark et al., 1999). Understanding large-scale cognitive processes has important implications beyond the laboratory, for example in real-world contexts we are likely to get lost in unfamiliar environments and require route directions to enable us to reach our desired destination.

Spatial descriptions of route directions enable a traveler to get from A to B in an unknown environment (Cassell, Kopp, Tepper, Ferriman, & Striegnitz, 2007; Nothegger et al., 2004). Descriptions are organised into a series of locations (based on visibility, cultural/ historical meaningfulness, distinctiveness, and permanence; e.g., the old church), prescriptive movements (e.g., go left), and descriptions (e.g., it's really steep; Cassell et al., 2007; Nothegger et al., 2004). Route directions specify salient points along the route (decision points), which require the traveller to make a decision about what direction to take (e.g., turn left or continue straight; Allen, 2000). The inclusion of these elements ensures the listener is on the correct path, and are therefore described in a way to disambiguate them from the other environmental characteristics and movement options available along the route (Cassell et al., 2007).

The acquisition of large-scale environmental knowledge becomes more accurate and efficient across childhood (Allen & Ondracek, 1995). Allen and Ondracek asked children between the ages 5 to 9 years to complete measures of memory and information processing speed, as well as spatial learning measures. As children got older, their memory and ability to recognise a scene increased in line with their memory ability. Children's acquisition of landmark information also increased, both in line with their increasing scene recognition and more generally with age. Drawing these findings together, Allen and Ondracek conclude that several of children's abilities to encode and retrieve information from complex arrays (such as environmental scenes) improve with age, leading to improvements in information acquisition (Allen & Ondracek, 1995). While these findings based on children's verbal responses increase our understanding about the trajectory of spatial knowledge acquisition, they may not tell the complete picture, as any spatial knowledge conveyed through gesture would be missed.

Speakers' Production of Gesture when Communicating Spatial Knowledge

Examining how people think and communicate about space while performing spatial tasks, particularly how they use words in combination with gestures, will enhance our understanding of cognitive processes, such as spatial cognition (Agostinho, Tindall-Ford, Ginns, Howard, Leahy, & Paas, 2015; Allen, 2000; Ehrlich, Levine, & Goldin-Meadow, 2006; Hu, Ginns, & Bobis, 2014). People use speech-gesture combinations to convey properties of route directions (e.g., location and movement information; Cassell et al., 2007; Emmorey, Tversky, & Taylor, 2000; Göksun, Goldin-Meadow, Newcombe, & Shipley, 2013). Establishing the relationship between speech and gesture, particularly during development, is important for understanding and clarifying the information link between speech and gesture and for evaluating gesture as a source of information about mental representations of environmental space (Allen, 2003).

Children produce gesture when conveying spatial information. During early childhood, the ability to convey route descriptions improves as language production, gesture proficiency, and the integration of gesture with speech develop (Sekine, 2009). In a longitudinal study, Sekine (2009) asked children between 4 to 6 years of age to convey the route they take from home to nursery school. At the age of 4 years, children did not use left / right terms but used gestures to directly and continuously indicate the actual route. As children got older their ability to express turns using speech and gesture combinations improved, with the overall number of turns reported and gestures produced increasing as they got older (Sekine, 2009). Over the two years, children's reporting of landmark information similarly increased, with almost 50% of children at age 6 producing left / right terms (Sekine, 2009). This study demonstrates that during development, cognitive changes such as language acquisition influence the production of speech and gesture, both separately and in combination. However, as this is the only study to date which examines how young children communicate large-scale spatial information, the current understanding of the relationship between speech and gesture in spatial communication during this critical period in development is limited.

During early childhood, children use gesture to convey other forms of spatial information such as mental rotation reasoning, Piagetian conservation reasoning and static object location (Alibali, Kita, & Young, 2000; Ehrlich et al., 2006; Nicoladis, Cornell, & Gates, 2008). For example, children aged 5 years were presented with training on mental rotation problems involving either practice, observed movement, or imagining the pieces moving together (Ehrlich et al., 2006). The effects of brief training were comparable to practice, with imagined movement training and observed movement training no better than practice at enhancing children's performance (Ehrlich et al., 2006). Furthermore, children frequently conveyed strategies in gesture that were not expressed in speech (Ehrlich et al., 2006).

Similarly, Alibali et al. (2000) asked children aged 4 to 6 years to solve and explain Piagetian conservation problems. In a second task, children described how two of the items used in the Piagetian task looked different. Children produced more non-redundant gestures (that is, gestures which convey information beyond speech content) during the explanation task than during the description task. In addition, Nicoladis et al. (2008) asked children between the ages of 2 and 5 to point in response to questions about the location of an object that was hidden either in rooms on the same floor or on a different floor. All children pointed to the location of the hidden object. However, the youngest children pointed to the route to rooms, while older children tended to point to the location of rooms. As children got older, they gradually used more spatial location terms than deictic gestures in response to questions about location (Nicoladis et al., 2008). Taken together, these findings suggest that gestures help young children to re-represent their perceptual and motor knowledge in the non-verbal form, as abstracted action. Furthermore, these studies suggest that the way children use gesture to communicate spatial knowledge changes with age, and that differences in gesture production reflect changes in children's understanding and conceptualisation of 'where'.

One possible explanation is that changes in the way children use speech and gesture to convey route directions as they get older reflect changes in spatial cognition (Blades & Medlicott, 1992; Iverson, 1999). Blind and sighted children aged between 9 and 18 years were asked to recall from memory the route to six familiar locations on the school campus, as well as a path through a desktop scene (Iverson, 1999). Regardless of visual status, participants who segmented the path with speech (i.e., broke the route down into a series of smaller steps defined by a sequence of landmarks) produced less gesture (Iverson, 1999). Direction and location information was conveyed through gesture more often than speech, while path and landmark information was conveyed through speech more often than gesture (Iverson, 1999). In a similar study, Blades and Medlicott (1992) presented adults and children aged between 6 to 12 years with a map and asked them to describe the route to someone who needed to walk the route. The ability to convey route directions improved with age, with 6-year-olds unable to give coherent route directions, providing little information (e.g., a list of landmarks). In contrast, 12-year-olds and adults successfully conveyed route directions using a sequence of roads and landmarks. Together, these studies suggest that as cognition develops our ability to effectively communicate our spatial knowledge from memory through speech and gesture improves.

Gesture production accompanying spatial knowledge communication continues throughout the lifespan. Existing research demonstrates that adults produce gestures when recalling spatial knowledge about cartoon events (Gillespie et al., 2014; Rauscher, Krauss & Chen, 1996), images or drawings (Morsella & Krauss, 2004; Wesp et al., 2001), and mental manipulation of objects (Chu & Kita, 2011; Göksun et al., 2013). For example, Wesp et al. (2001) asked adults to describe a still life drawing in detail. Adults produced more gesture when describing the painting from memory compared with describing a visible painting. In a series of experiments, Chu and Kita (2011) asked adults to decide the similarity of the target object with one of two other objects (i.e., a mental rotation task). Adults' increased reaction time, error rate and gesture production for objects rotated 120 and 240-degrees compared with objects rotated 60 and 300-degrees indicates greater difficulty for rotations of 120 and 240 degrees. When encouraged to gesture, adults solved more problems correctly than when merely allowed to gesture (i.e., spontaneous gesture production). In addition, adults produced more spontaneous gesture when they had difficulties solving the mental rotation problem. This study suggests that difficulty in a spatial visualisation task triggers spontaneous co-thought gestures, which then improve task performance when gesture production occurs (Chu & Kita, 2011). As task familiarity increases, gestures become internalised and gesture frequency decreases. Taken together, these studies suggest that speakers produce gesture when communicating spatial knowledge and that producing gesture benefits speakers' thought processes and helps communicate spatial information. Of primary interest to the current studies however is the production of gestures with route directions.

Existing research has demonstrated that adults produce a variety of gestures when conveying route directions from memory. For example, Allen (2003) asked undergraduates to convey route directions to different locations on campus. When conveying directional information (i.e., left / right / straight), adults typically produced deictic / pointing gestures.

Iconic and beat gestures were also produced but to a lesser extent. The rate of gesture production increased as speech increased, suggesting that producing gestures facilitated the speech production process (Allen, 2003). Adults' production of a variety of gestures also suggests that speakers' gestures which accompany route direction information reflect their underlying knowledge base and cognitive processes.

While research is limited, Cassell et al. (2007) demonstrated that the gestures adults produce when conveying route direction knowledge can represent aspects of the environment such as salient location information. Cassell et al. asked adults to learn a route between two points on campus from a map. Adults were then asked to convey this route to someone unfamiliar with the campus to enable route navigation without the use of external aids (e.g., a map). The shape, location, and orientation of the gesturing hand corresponded to the visual aspects of the spoken referents. For example, vertically orientated gestures with a flat hand shape corresponded to objects with an upright plane referred to in speech. Gestures where the fingers were neither pointing up or down nor the palm necessarily horizontal, corresponded to spoken referents with a salient horizontal plane. Adults' production of gesture suggests a relationship between the form a gesture takes and the concrete spatial characteristics of the referent object (Cassell et al., 2007). Importantly, evidence of a relationship between the form of a gesture and the associated speech content suggests that we can learn a lot about speakers' spatial cognition by examining the relationship between a speaker's speech content and the accompanying gestures they produce when conveying route direction information.

Gesture production facilitates spatial cognition and communication. Adults use gesture to facilitate the communication of challenging or complex spatial information from memory (Emmorey et al., 2000; Suppes, Tzeng, & Galguera, 2015). Emmorey et al. (2000)

asked both hearing and deaf American Sign Language users to memorise a map of either a town or convention centre and then describe it to someone unfamiliar with the area. Adults used iconic gestures to represent location information, including their position in relation to other locations (Emmorey et al., 2000). Similarly, Suppes et al. (2015) videotaped adults describing simple and complex apartment layouts from memory. When describing complex compared to simple layouts, speakers used more imagistic gestures, particularly more iconic-deictic gestures (that is, hand movements that represent both an object or action and direction or location). In other words, as task difficulty increased, the rate of complex imagistic gestures also increased. Importantly, the rate and production of imagistic gestures provides evidence in line with embodied cognition theory, that gestures may be used by speakers to off-load cognitive work to facilitate the communication of complex spatial information. It is also possible that speakers produced more iconic-deictic gestures when describing the complicated layout because they needed to express complicated objects. Therefore, gestures might not contribute to reducing the cognitive load.

As previously discussed (see sections: The Role of Gesture in Communication for Speakers and Listeners, and The Function of Gesture in Communication), verbal and gestural communication combine to support cognitive processes. Complex spatial tasks such as conveying route directions require speakers to draw environmental knowledge from memory and produce coherent verbal directions, utilising multiple cognitive abilities including verbal and spatial abilities (Vanetti & Allen, 1988). Spatial abilities are skills (i.e., visualisation, spatial relations, and orientation) necessary to anticipate and track environmental changes and remain orientated within the environment (Chu & Kita, 2011; Göksun et al., 2013; Hostetter & Alibali, 2007; Hostetter & Skirving, 2011; Hegarty et al., 2006; Vanetti & Allen, 1988). Vanetti and

Allen (1988) asked undergraduates to complete measures of spatial cognition and campus knowledge before conveying route directions from the testing room to a location on campus. Individuals reporting high spatial abilities produced more efficient routes than individuals reporting low spatial abilities. Individuals with higher verbal abilities included more description and information regarding decision points (that is, points at which decisions about direction are made), than individuals with lower spatial abilities. Most adults produced gestures when conveying route directions, with individuals lower in verbal ability tending to produce more gestures than those with higher verbal ability (Vanetti & Allen, 1988). This study suggests that both spatial and verbal abilities play important but distinct roles in the communication of route direction information (Vanetti & Allen, 1988). In spatial tasks, speakers' gestures express speakers' thoughts by re-representing spoken actions and objects. Gestures may also be particularly beneficial for listeners in supplementing and disambiguating the spoken spatial message.

Listeners Use Speakers' Gesture Production During Spatial Knowledge Communication

Existing research has demonstrated that gesture enhances learner's encoding of spatial information (So, Ching, Lim, Chen, & Ip, 2014; So, Shum, & Wong, 2015). So et al. (2015) presented adults with visual step-by-step route information and then instructed participants to rehears the route either using gesture and speech, speech only, gesture only, or no rehearsal. Whether participants' rehearsal was accompanied by spatial language or not, participants encouraged to gesture during route rehearsal reconstruct more of the route with sticks than participants not encouraged to gesture during rehearsal. This finding suggests that producing gestures when rehearsing spatial information is more effective than spatial language in facilitating the encoding and subsequent recall of spatial information. It does not examine, however, the role of gesture during verbal spatial information communication on listener's encoding. Consequently, gestures may be particularly beneficial for listeners when they accompany spatial messages such as route direction information.

As previously mentioned, the expression of speakers' route knowledge comes from previous perceptual experience transformed into the verbal production of route directions (Allen, 2000). In contrast, listeners must create a mental model of the route based on the verbal description and accompanying gestures (Allen, 2000; Wochinger & Boehm-Davis, 1995). Moreover, when navigating the route, listeners must compare the real-world features (perceptual experience) to their imagined mental representations (Allen, 2000; Wochinger & Boehm-Davis, 1995). For listeners, this requires interpretation of speakers' navigation information, a continuous visual search of the environment for relevant features, matching of imagined mental representation of route features to actual route features, and estimating time and distances (Allen, 2000; Wochinger & Boehm-Davis, 1995).

To date, only one study has investigated the effect of a speaker's gesture on listeners' successful route recall and physical navigation (Austin & Sweller, 2014). In research preceding this PhD, we presented preschool-aged children (4 to 5 years) and adults with either no gestures, beat gestures, or both imagistic and non-imagistic gestures (a combination of iconic, deictic, metaphoric and beat) accompanying route directions through a desktop spatial array. Children presented with either beat or a combination of gestures recalled more route information than did children presented with route directions accompanied by no gestures. For adults, however, gestures did not enhance small-scale route direction comprehension and recall.

The examination of small-scale route direction comprehension and recall when gestures accompany verbal route information is a fundamental first step in understanding the role that gesture plays for listeners in the context of spatial tasks. However, as previously mentioned, small-scale spatial task performance may not necessarily generalise to performance on large-scale spatial tasks. Large-scale tasks place a larger cognitive demand on learners than small-scale, because the listener needs to construct the mental representation of the environment without previous exposure to that environment. It is possible that gestures will be more beneficial for large-scale than small-scale tasks, demonstrating a larger effect when the task is harder. A beneficial effect of gesture for large-scale but not small-scale environments will enhance our understanding of the role gesture plays in cognitive processes during spatial communication. Therefore, further examination of the role of gesture in communicating spatial information for listeners is needed to understand the cognitive processes involved.

The Function of Gesture in Spatial Communication

The Function of Gesture in Spatial Communication for Speakers

As previously mentioned (see section: The Function of Gesture in Communication) embodying thought processes through gesture production is thought to increase the cognitive resources available to concurrent thought processes (e.g., memory; Goldin-Meadow et al., 2001; Just & Carpenter, 1992; Wilson, 2002). Gestures re-represent action in the form of abstracted action. As a result, offloading cognitive work into the environment through abstracted actions may be particularly beneficial during spatial communication. As with other tasks, gesture may serve two functions for speakers performing spatial tasks: help speakers translate spatial knowledge / information into speech and / or directly communicate spatial location / movement information, thereby eliminating the need to translate this information into speech (Hostetter & Alibali, 2008; Wilson, 2002).

Producing gesture during spatial task performance grounds thought processes in the environment, allowing speakers to offload cognitive work, thereby helping speakers translate spatial knowledge / information into speech (Tversky, 2011, Wilson, 2002). For example, communicating route direction information by pointing to the right accompanying the phrase “go right at the office”, reduces the resources needed by the speech production processes. In turn, this makes more resources available for recalling the route / maintaining the mental representation of the route in memory, thereby facilitating spatial knowledge communication. At the same time, gestures provide speakers with feedback on their thought processes by reflecting mental representations (Goldin-Meadow & Alibali, 2013; Madan & Singhal, 2012; Wilson, 2002). While gestures facilitate the management and allocation of mental resources, gestures may also enhance the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005).

During spatial communication, gestures may also play a functional role in the construction of phrases and therefore, the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing a gesture portraying automatic sliding doors to indicate a door, disambiguates it from a door which might be accompanied by a gesture portraying the turning of a door handle. In this way, producing gesture provides individuals with a means to communicate spatial knowledge and ideas (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007; Madan & Singhal, 2012; Wilson, 2002). Importantly, the embodiment of thought processes through gesture production may have multiple functions for speakers that are not mutually exclusive.

As stated above, gesture’s form, position and movement may serve multiple functions during spatial task performance (Kok et al., 2016). For example, gesture may be used to reference and represent landmarks, convey size and shape of space, or indicate a direction for movement and thus support spatial cognition (Kok et al., 2016). That is, gesture provides the cognitive system with a stable external physical and visual presence that can provide speakers with a means to think and communicate with (Pouw et al., 2014). Understanding the integration of speech and gesture when conveying spatial information will lead to a deeper understanding of thought processes, particularly those involved in encoding, retaining and recalling spatial knowledge. However, both sides of the communication dyad need to be considered when examining the role of gesture in spatial communication. For speakers, gestures help facilitate thought processes and the communication of knowledge. However, speakers' gestures may also benefit listeners, facilitating the encoding, retention, and recall of the speaker's spoken message.

The Function of Gesture in Spatial Communication for Listeners

The construction of an imagined mental model of route directions places considerable demands on memory, particularly for unfamiliar environments (Allen, 2000). If task load is unmanageable due to the length of route instructions or due to an unfamiliar environment, then some information may never be encoded (Allen, 2000). Therefore, there are two pathways whereby the presence of gesture accompanying route direction information may facilitate listener encoding and subsequent recall. Gestures may scaffold speech comprehension by conveying route elements through pointing, depicting gestures, or through movement (Tversky & Kessell, 2014). In this way, speakers' gestures act to disambiguate or reinforce the spoken message, and may be particularly beneficial when spoken route directions are complex, extensive or incomplete. By clarifying spoken language, gestures can help to create transient maps that preserve spatial route properties such shape and movement, thereby freeing cognitive resources for concurrent processes such as memory (Tversky & Kessell, 2014).

In addition, embodied cognition suggests that processing information conveyed in speech and gesture activates the same perceptual and motor states involved in gesture production, thereby facilitating the generation of an imagined mental representation of the route (Alibali & Hostetter, 2010; Just & Carpenter, 1992; Madan & Singhal, 2012). In this way, listeners may create a richer and more elaborate imagined mental representation of route directions accompanied by gesture than of route directions conveyed through speech alone. Given that people have limited mental resources, a richer imagined mental representation of route information reduces the information processing demands of speech comprehension, thereby increasing the resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992). For listeners, gestures accompanying route direction information may reduce the spatial information processing demands and result in increases in resources for task demands such as verbal recall and physical route navigation.

Aims of the Thesis

Previous research has consistently demonstrated that young children and adults produce gestures when conveying spatial information (e.g., Allen, 2003; Sekine, 2009). In the context of describing the environment, past research has shown that the form and shape of gesture maps onto environmental features (e.g., Cassell et al., 2007), and that both children and adults produce gestures when conveying route directions from memory (e.g., Blades & Medlicott, 1992). Further, research has repeatedly demonstrated that speakers' gestures enhance listener comprehension and recall of words and sentences (e.g., Thompson et al., 1998), and there is also preliminary research to show the same pattern of findings with spatial information: especially route directions (e.g., Austin & Seller, 2014). To date, however, no work has compared the gestures speakers produce accompanying large-scale route directions in terms of whether they can explain differences in successful route navigation for listeners. Theoretical explanations of gesture production have not yet comprehensively explained the function for the production of all types of gesture (e.g., beat gestures), nor is there yet a comprehensive framework for explaining the function and mechanisms of gestures accompanying spoken messages for listeners. These gaps are problematic, as different gestures have different communicative value. Therefore, different types of gesture might be associated with cognitive processes to different degrees. For example, there is some evidence that iconic gestures have different cognitive and communicative value for both speakers and listeners depending on the degree of information they convey consistent with or beyond the spoken message (e.g., So et al., 2012).

By reviewing the extant literature throughout this introduction, it has been shown that people produce gestures when performing spatial tasks such as conveying route directions that gestures correspond to environmental features, and separately in non-spatial literature, that gestures accompanying speech enhance listeners' task performance. The central focus of this thesis is to integrate these associations. This thesis will present three distinct empirical works that together explore the role of gesture in communication for speakers and listeners. In order to better establish how gesture accompanying spatial information is beneficial, it will investigate two potential functions: the extent to which gestures *help* speakers translate spatial knowledge into speech and / or *eliminate* the need to translate knowledge into speech, as well as the extent to which gestures accompanying spatial information *help* listeners comprehend and subsequently recall the spoken message, particularly during development. Furthermore, in order to properly investigate the role that cognitive ability plays in moderating the potential benefit of gesture for adults, and given the lack of research in the area, it will examine the influence an individual's spatial ability, vocabulary, and memory have on information conveyed through both speech and gesture.

Specifically, this thesis aims to (1) investigate the relationship between types of speech phrases and types of gesture during route direction communication for both young children and adults, (2) investigate whether gestures accompanying route direction information can enhance the recall and successful task performance for young children, and (3) investigate whether gestures accompanying route direction information can enhance verbal recall and successful task performance for adults, and to what extent cognitive abilities such as vocabulary and spatial ability influence the uptake of information conveyed through the two modalities.

Thesis Structure

This introduction has reviewed the relevant literature and introduced the thesis in the context of prior work in the field. Chapter 2 presents an empirical paper titled *Gesturing Along the Way: Adults' and Preschoolers' Communication of Route Direction Information*, which has been published in Journal of Nonverbal Behavior. In this paper, a cross-sectional experiment is described in which pre-schoolers and adults were asked to convey route direction information from memory, addressing Aim 1. Specifically, this experiment: 1) explored the speech and gesture produced by children aged three to five years and adults, in order to establish the relationship between types of speech phrases and the types of gestures which accompany them; 2) explored developmental differences between children and adults, and 3) examined the effect of task purpose on the relationship between speech and gesture.

Chapter 3 presents an empirical paper titled *Getting to the Elephants: Gesture and Preschoolers' Comprehension of Route Direction Information*, which has been published in

Journal of Experimental Child Psychology. In this paper, a cross-sectional experiment is described in which children were presented with verbal route directions and depending on assigned condition, accompanying gestures, addressing Aim 2. Specifically, this experiment examined the effect of gestures accompanying spatial route direction information on recall for preschool aged children. Finally, Chapter 4 presents an empirical paper titled *Pointing the Way Forward: Gesture and Adults' Comprehension of Route Direction Information*, which has been submitted to Journal of Experimental Psychology: Applied. In this paper, two cross-sectional experiments are described in which adults were presented with verbal route directions and depending on assigned condition, accompanying gestures, addressing Aim 3. Specifically, these experiments examined the effect of gestures accompanying spatial route directions on recall for adults, and examined whether different types of cognitive abilities moderate the beneficial effect of gestures accompanying spatial information for listeners. Together, this thesis explores the nature of gesture production in the context of spatial information communication, and the effect of producing gestures accompanying spatial information on listeners' encoding, retention, recall and task performance at different points in development.

Table 1

List of Papers and Publication Status

Chapter Title	Journal	Status
Gesturing Along the Way: Adults' and Preschoolers' Communication of Route Direction Information	Journal of Nonverbal Behavior	**Accepted for publication, 2017**
Getting to the Elephants: Gesture and Preschoolers' Comprehension of Route Direction Information	Journal of Experimental Child Psychology	**Published, 2017**
Pointing the Way Forward: Gesture and Adults' Comprehension of Route Direction Information	Journal of Experimental Psychology: Applied	**Under review**

Chapter 2: Gesturing Along the Way: Adults' and Preschoolers' Communication of Route Direction Information

Published as: Austin, E.E., Sweller, N. (2018) Gesturing along the way: adults' and preschoolers' communication of route direction information. *Journal of Nonverbal Behaviour*, vol. 42, pp. 199–220. https://doi.org/10.1007/s10919-017-0271-2.

The first empirical work of the thesis is presented in this chapter. It aims to explore the gestures and speech preschool aged children and adults produce accompanying spatial route directions and the extent of any developmental differences, as well as the effect of task purpose on adults' communication of spatial route directions. Specifically, this chapter quantifies the degree of relationship between types of speech phrases and the types of gestures which accompany them, explores developmental differences between the age groups, and examines the role of task purpose in eliciting spatial information. As was discussed in Chapter 1, the theoretical approach to gesture production suggests that the speaker's production of gestures, as the externalisation / embodiment of thought processes, serves two functions: gestures help translate knowledge into speech and / or eliminate the need for speakers to translate knowledge into speech. If the first were true, gestures and their associated speech should convey the same information. If the second were true, gestures should convey information beyond speech content. The extent of the variation, and where it exists, will help researchers better understand the function of gesture production for speakers at different ages by demonstrating how age-related differences impact on the degree of information overlap between the gesture and speech produced. Moreover, the extent and type of differences will help researchers better understand the function of task purpose for speakers' conceptualisation of space by demonstrating how task purpose impacts on the relationship between gesture and speech produced.

The work in this chapter underpins the remaining three empirical works in this thesis, informing the choice of speech and gestures used as stimuli in the remaining individual empirical works. In addition, it characterises the speech and gestures young children and adults produce when conveying spatial route direction information from memory, and the nature of the relationship between types of speech phrases and types of gesture, which directly addresses the first aim of the thesis.

Student Statement of Contributions

I was the major contributor to this co-authored paper. I was responsible for developing the conceptual argument and study design, and did this in consultation with my primary supervisor, Naomi Sweller. I also collected all data and conducted the statistical analyses with input and advice from Naomi Sweller. I drafted the first version of the manuscript, and Naomi Sweller provided feedback and suggestions on multiple versions of the manuscript.

As outlined in Chapter 1, this paper has been accepted for publication by the *Journal of Nonverbal Behavior*. The full reference is:

Austin, E. E., & Sweller, N. (in press). *Gesturing along the way: Adults' and preschoolers' communication of route direction information.* Journal of Nonverbal Behavior.

Gesturing Along the Way: Adults' and Preschoolers' Communication of Route Direction Information

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Submission date: 19th January 2016

Resubmission date: 6th July 2016

Resubmission date: 24th March 2017

Resubmission date: 27th June 2017

Abstract

Speakers routinely produce gestures when conveying verbal information such as route directions. This study examined developmental differences in spontaneous gesture and its connection with speech when recalling route directions. Children aged 3-4 years and adults were taken on a novel walk around their preschool or university and asked to verbally recall this route, as well as a route they take regularly (e.g., from home to university, or home to a park). Both children and adults primarily produced iconic (enacting) and deictic (pointing) gestures, as well as gestures that contained both iconic and deictic elements. For adults, deictic gestures typically accompanied phrases both with description (e.g., go around the green metal gate) and without description (e.g., go around the gate). For children, phrases with description were more frequently accompanied by iconic gestures, and phrases without description were more frequently accompanied by deictic gestures. Furthermore, children used gesture to convey additional information not present in speech content more often than did adults, particularly for phrases without description.

Keywords: gesture, spatial, recall, preschoolers, adults

Gesturing Along the Way: Adults' and Preschoolers' Communication of Route Direction Information

Verbal and non-verbal communication enables us to share knowledge such as where to find the best food and how to avoid danger (e.g., Tversky, 2011). While verbal communication allows us to directly convey a wealth of information such as physical object structure, form, and position, as well as abstract meanings, mood, and attitude, it does not occur in isolation (Tversky, 2011). Whether we are communicating face to face or over the phone, verbal communication is often accompanied by nonverbal behaviors such as hand gestures (Alibali, Heath, & Myers, 2001; Wesp, Hesse, Keutmann, & Wheaton, 2001). These hand gestures can both reflect and affect thinking by externalizing our thought processes (Segal, Tversky, & Black, 2014; Wilson, 2002). Gestures produced by speakers can, therefore, provide speakers with feedback on their own thought processes, as well as provide listeners with important information about a speaker's thoughts beyond the content of speech (Goldin-Meadow & Alibali, 2013; Kita & Özyürek, 2003; Kita, Özyürek, Allen, Brown, Furman, & Ishizuka, 2007; Madan & Singhal, 2012;Mcneill, 1992; Sekine & Kita, 2015; So, Kita, & Goldin-Meadow, 2009).

The embodiment of thought processes through gesture may serve two functions: (1) help speakers translate ideas into speech and/ or (2) eliminate the need to translate ideas into speech at all (Hostetter & Alibali, 2007; Wilson, 2002). If a gesture is used to help a speaker translate an idea into speech, then there is likely to be a large degree of overlap in the content of the gesture and the associated speech phrase. On the other hand, if a gesture removes the need to translate ideas into speech at all, then the gesture is likely to present additional information, beyond that contained in the speech phrase. Although these two possibilities are not mutually exclusive, there is limited research examining the degree of additional information conveyed by gesture beyond speech, or the relationship between types of gesture and speech content (Hostetter & Alibali, 2007). Examining the relationship between speech and gesture will enhance our understanding of the role gesture plays in cognition and communication, and the construction of meaning beyond speech (Tversky, 2011).

Gesture Definitions

Gestures can represent and communicate aspects of thought to listeners more directly than can words (Tversky, 2011). For example, iconic gestures, such as pantomiming a tall box, can convey object characteristics such as height, thereby disambiguating the target object from other objects through hand shape (Cassell, Kopp, Tepper, Ferriman, & Striegnitz, 2007). Deictic gestures, such as pointing to the left, convey movement, direction, or relational information to the listener (Cassell et al., 2007). Metaphoric gestures, such as enacting "balancing" accompanying dialogue about comparisons, convey abstract concept characteristics (Allen, 2003; McNeill, 1992). In contrast, beat gestures are simple rhythmic hand movements which go along with the rhythm of speech but have no apparent semantic meaning (Allen, 2003; McNeill, 1992). However, beat gestures may function as a discourse marker by indicating other communicative aspects such as emphasis (Allen, 2003; McNeill, 1992, 2005).

Iconic, deictic and metaphoric gestures can be further separated into gestures which allow individuals to express information both consistent with (i.e., redundant) and beyond (i.e., non-redundant) the phrases they accompany (Alibali, Kita, & Young, 2000; Tversky, 2011). Redundant gestures reflect the meaning of the words they accompany (Alibali et al., 2000). For example, "the grass area is flat" accompanied by a gesture indicating a flat surface, conveys the same information in gesture as in speech. Conversely, non-redundant gestures (sometimes called gesture-speech mismatches) go beyond the words they accompany, communicating additional information more directly and offering a second window into the speaker's thinking (Alibali, Flevares, & Goldin-Meadow, 1997; McNeill, Cassell, & McCullough, 1994). For example, "go past the front of the building" with a gesture indicating a large rectangular box to the right conveys information beyond the speech content, namely that a rectangular building is on the right.

Previous research has shown that gestures can convey information beyond speech content, with some gestures conveying more information than others (Beattie & Shovelton, 1999). This has been demonstrated with iconic gestures relating to particular semantic features (e.g., relative position and size of objects), which can convey information beyond speech content (Beattie & Shovelton, 1999; Cassell, McNeill, & McCullough, 1999). Similarly, Cassell et al. (2007) reported a relationship between the form of a gesture and the characteristics of the entity to which it refers. While these findings suggest that some gestures relate meaningfully to the speech they accompany and that they can convey information beyond speech content, literature is yet to address the relationship between other gesture types (e.g., deictic and metaphoric) and the speech they accompany. These findings also suggest, however, that the commonly used practice of binary coding (i.e., placing gestures into redundant and non-redundant categories) does not pick up differences in the extent to which gestures communicate additional information (i.e., extent of redundancy; Alibali et al., 2000; Beattie & Shovelton, 1999; Cassell et al., 1999; Kita et al., 2007; McNeill, 1992, 2005). Examining the relationship between speech and a range of gestures, as well as the degree of redundancy between information conveyed between speech and gesture will further enhance our understanding of gestures as an embodiment of speakers' mental representations.

Gesture Production in Adults

To date, research has primarily focused on the rate, type and frequency of gestures, and not investigated the relationship between types of gesture (e.g., iconic, deictic) and the content of the phrases they accompany (Hostetter & Alibali, 2007; Hostetter & Skirving, 2011; Morsella & Krauss, 2004; Tversky, 2011; Wesp et al., 2001). For instance, Hostetter and Skirving (2011) reported that adults presented with an animated cartoon of an event and a verbal description of the event produced more iconic and deictic gestures accompanying verbal recall than those who did not watch the cartoon. Similarly, adults presented with images of abstract or recognizable objects, produced more gesture when describing images from memory compared with visually accessible images, and when describing difficult to encode images than easy to encode images (Morsella & Krauss, 2004). In addition, the frequency of adults' gesture production changes depending on task demands/ conditions, as adults produced fewer gestures when retelling a story to a listener who has heard the story before than when conveying it to a listener for the first time (Galati & Brennan, 2013). While these studies demonstrate that adults produce a range of gestures when recalling information and that the rate of gestures increases when memory is challenged or when conveying novel information to listeners, they do not shed light on gesture's relationship with speech content. Examining the extent of gesture redundancy (i.e., degree of additional information conveyed by gesture beyond speech) and the relationship between types of gesture and speech content will clarify the role of different types of gesture in externalizing thought processes and conveying meaning.

The function of gesture production for adults. Gestures accompanying verbal communication reflect and affect a speaker's cognition by externalizing thought processes (Wilson, 2002), providing benefits to the speaker themselves. The form and shape gestures take reflect speakers' thought processes, providing them with feedback on their thoughts (Goldin-Meadow & Alibali, 2013; Madan & Singhal, 2012). Alternatively, producing gestures reduces the overall load on cognitive resources by reducing the cognitive workload of speech, thereby freeing resources for other cognitive processes such as memory (e.g., word retrieval; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Just & Carpenter, 1992; Wilson, 2002). In this way, the embodiment of speakers' cognition through gesture benefits speakers' thought processes and helps communicate information. Producing gestures may benefit speakers for some tasks more than others, with existing research reporting that speakers produce more gestures when communicating spatial information than non-spatial information (Rauscher, Krauss, & Chen, 1996).

Gesture production, spatial tasks and adults. Communicating spatial information such as describing an object's location, or providing route directions, enables us to interact with and communicate about the physical world (Taylor & Tversky, 1996). For instance, verbal route directions are narratives, comprised primarily of propositions containing spatial information such as prescriptive movements (e.g., go left), locations (e.g., the gate on your right), movement descriptions (e.g., take the sharp left) and location descriptions (e.g., the green metal gate on your right; Daniel, Przytula, & Denis, 2009). Route knowledge comes from processing perceptual input as we move through environments which we then transform into verbal route directions (Allen, 2000; Cassell et al., 2007).

Adults accompany verbal route directions with gestures, particularly deictic and iconic gestures (Allen, 2003). The visual characteristics of these gestures often reflect the spatial features of the object referred to in speech (e.g., a flat hand shape vertically orientated might refer to objects with an upright plane), or the relationship between two locations (e.g., using one hand to symbolize a location and the other hand to convey a landmark relative to that location; Cassell et al., 2007; Emmorey, Tversky, & Taylor, 2000). Together these studies demonstrate through the rate, synchrony with words, and types of gestures produced, that adults both produce gestures accompanying spatial route information and that hand shape may act to disambiguate a location (Allen, 2003; Cassell et al., 2007). While this suggests the existence of an informational relationship between speech and gesture, the dimensions of the information conveyed in speech and gesture independently or together has not been established. Furthermore, existing research does not indicate the effect of task purpose during spatial communication on the characteristics of gestures accompanying spatial information. Importantly, existing research does not indicate the characteristics of gestures accompanying spatial information produced by children.

Gesture Production in Children

As noted above, gestures are a valuable source of information about a speaker's thoughts. It is important therefore to clarify the role of gesture in cognition and communication as language and gesture production develop, i.e. during early childhood (Alibali et al., 1997; Church & Goldin-Meadow, 1986). Children as young as 8 months produce gestures, allowing them to engage with and communicate about their immediate world before they have the words to do so (Bates, 1976; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Capirci & Volterra, 2008; Goldin-Meadow & Alibali, 2013; Iverson & Goldin-Meadow, 2005). While children reach linguistic milestones at different rates, gesture and language development are thought to be related, with infants transitioning from simple pointing gesture only to single word utterances, to single word plus gesture combinations as their vocabulary develops (Adams, Bourke, & Willis, 1999; Iverson & Goldin-Meadow, 2005; Özçalışkan & Goldin-Meadow, 2010). In addition, the number of speech plus gesture combinations children produce increases significantly between 14 to 22 months of age, with gestures increasing in variety and complexity over time (Behne, Carpenter, & Tomasello, 2014; Özçalışkan & Goldin-Meadow, 2005). Producing gestures enables infants to communicate multiple pieces of information and meanings before they have the vocabulary to do so, thereby facilitating language learning through exposure to new words via social interactions (Goldin-Meadow & Alibali, 2013; Iverson & Goldin-Meadow, 2005; McNeill, 1992).

The association between gestures and the context of spoken words grounds language learning in the physical world (Yu, Ballard, & Aslin, 2005). Between the ages 10 months and 24 months children observed during play and meal time often used gesture to refer to objects, transitioning with age from using gesture only to using speech plus gesture or speech only, to refer to objects (Iverson & Goldin-Meadow, 2005). Consistent with this change, children’s early word meanings are perceptual (i.e., based on the concrete environment) and not functional (i.e., based on abstract relatedness) with children learning nouns (e.g., bed, cat) faster than verbs (e.g., painting; Gentner, 1978; Tomasello, Akhtar, Dodson, & Rekau, 1997; Yu et al., 2005). Children’s vocabulary continues to expand and by age 2, children’s vocabulary repertoire has between 50 to 600 words (Cameron & Xu, 2011). Between ages 3 and 5 years children’s ability to communicate and comprehend speech and gesture further improves, as the foundations of adult syntax and sentence structure are acquired (Cameron & Xu, 2011; O'Reilly, 1995).

The function of gesture production for children. During the language learning years gestures may perform a functional role in the construction of phrases and the expression of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing the iconic gesture: *both hands flapping*, to indicate the animal “bat”, disambiguates it from a sport based “bat” which they might accompany with a striking motion (Kidd & Holler, 2009).

Producing gestures provides preschoolers with a means to communicate ideas beyond their current vocabulary and provides their listeners with insight into the content and extent of their knowledge and cognitive development (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007; Madan & Singhal, 2012; Wilson, 2002). Language, and therefore gesture, also plays a fundamental role in the development and communication of theory of mind and spatial perspective taking, an important conceptual change taking place between ages of 2 ½ and 5 years (Astington & Jenkins, 1999; Flavell, Everett, Croft, & Flavell, 1981; Schober, 1993; Selman, 1971; Wellman, Cross, & Watson, 2001).

Theory of mind is the understanding that others and oneself have mental states (e.g., desires, emotions, intentions), and the realization that these mental states may or may not reflect reality (i.e., false beliefs; Astington & Jenkins, 1999; Wellman et al., 2001). Similarly, spatial perspective taking is the ability to infer or recognize that the other person may see an object that the child does not see, or vice versa, and that an object may have a different appearance depending on distance and the side the object is seen from (Flavell et al., 1981; Schober, 1993). Cognitive abilities, such as theory of mind and spatial perspective taking skills, undergo considerable development during the preschool years, with children expressing their knowledge and understanding through both speech and gesture (Bretherton, McNew, & Beeghly-Smith, 1981). The gestures children produce indicate to others the extent and content of children's current knowledge available for communication before they have the words to do so (Bretherton et al., 1981). Due to limitations in language ability, we may be able to more accurately assess children's cognitive development through examining their gestures over and above their speech content. Examining the gestures children produce during tasks such as spatial communication, which require children to apply their theory of mind and perspective taking skills, will provide a clearer picture of how their speech and gestures combine to convey information they cannot express through speech alone.

Gesture production, spatial tasks and children. During early childhood, gestures offer a way for speakers to organize and package ideas, as well as a way to convey semantically complex information beyond their current language skills (Özçalışkan & Goldin-Meadow, 2010). In this way, the gestures preschoolers produce become an important source of information about changes in spatial cognition as language develops (Just & Carpenter, 1992; Nicoladis, Cornell, & Gates, 2008). Children transition between the ages of 2 to 5 years from pointing to the route to an object's location, to pointing to the location of the room in which the object is located (Nicoladis et al., 2008). This suggests that children’s conceptualization and communication of space changes as language skills and cognition develop. Examining differences between preschoolers’ and adults’ communication of environmental knowledge will provide insight into early conceptualization of space and how these change during language development.

When communicating environmental knowledge, while children aged 8, 9 and 10 years and adults rarely conveyed information in speech without also communicating that information in gesture, they also convey a lot of information in gesture that was not present in speech (Sauter, Uttal, Alman, Goldin-Meadow, & Levine, 2012). Looking at younger children, when recalling the route from nursery school to home, 4-year-old children omitted important movement and location information compared with 6-year-olds (Sekine, 2009). For example, children aged 4 years did not use left/ right terms, conveying the actual route directly and continuously through gesture. By 6 years of age, 50% of children used left/ right terms and produced more speech-only route direction phrases than phrases containing both speech and gesture (Sekine, 2009). The overall number of turns reported and gestures produced increased as children got older, with 6 year olds less likely to fail to mention a turn compared with younger children (Sekine, 2009). This age difference suggests that as vocabulary and cognition develop, the ability to effectively communicate route directions improves. It does not, however, account for the role different types of gestures play in the communication of route directions. If gestures offer a way for young children to communicate spatial concepts that they do not yet have the words to express, then it is important to examine the types of gestures preschool aged children produce when conveying route directions, the degree of gestural redundancy, and how those gestures accompany the verbal communication of route directions (Iverson & Goldin-Meadow, 2005).

The Current Study

The preschool years constitute a critical time for language development. Gestures, therefore, become an important source of information about a child's developing spatial knowledge and cognitive processes. Gestures are also an important source of information about adults' spatial conceptualization and cognitive processes. The current study was designed to examine the gestures produced by children and adults while conveying spatial route directions, thereby examining the communication of environmental thinking as language and cognition develop. It is important to note there is some evidence that task purpose influences adults' gesture production (e.g., Galati & Brennan, 2013) and how adults process and subsequently recall spatial information (e.g., Taylor, Naylor, & Chechile, 1997). To account for potential differences in speech and gesture production due to task instruction, two adult conditions were included in the study design. Some adults were given the same task instructions as children and some adults were given task instructions in language more appropriate to adults. Therefore, the current study was designed to explore differences in adults' speech and gesture production depending on task instruction.

Consequently, there are five aims of this study: 1) to document the types of spontaneous gestures preschoolers and adults produce when recalling route directions (descriptions); 2) to compare the types of gestures produced by children vs. adults; 3) to examine the additional information presented through gesture (level of redundancy) in relation to different speech phrases; 4) to examine the relationship between the types of gesture produced and the associated phrase content and 5) to examine whether any developmental differences noted above in aims 1 – 4 hold when adults are a) given the same task instructions as children compared with b) given task instructions in language more appropriate to adults.

If gestures allow individuals to convey information beyond their current vocabulary, then we would expect the gestures produced by children (who have a more limited vocabulary) to depict information beyond speech content to a greater extent than gestures produced by adults (who have a more complete vocabulary). Differences in gesture redundancy between children and adults would imply differences in cognitive processing of environmental information. In addition, if gestures help speakers translate ideas into speech and/ or eliminate the need to translate ideas into speech at all, then we would expect deictic (pointing) gestures to accompany speech without descriptive content to a greater extent than speech with descriptive content, and iconic gestures (which can depict concrete descriptive information) to accompany speech with descriptive content to a greater extent than speech without descriptive content. Finally, due to the exploratory nature of the effect of task instruction on adults' speech and gesture production, there were no directional hypotheses for the effect of task purpose on adults speech and gesture production.

Method

Participants

Thirty-three children were recruited from preschools in Sydney, Australia (19 boys and 14 girls, mean age = 4 years 7 months, *SD* = 5 months, range = 3 years 10 months to 5 years 5 months). Seventy-five adults were recruited from an introductory psychology unit at Macquarie University (38 males and 37 females, mean age = 21 years, *SD* = 5, range = 18 to 52). Two children were removed from analysis due to a failure to provide either verbal or gestural responses. The final sample comprised of 31 children and 75 adults. This study was approved by the Macquarie University Faculty of Human Sciences, Human Research Ethics Committee (HREC). Preschool directors and parents/ guardians of the children received an information sheet describing the purpose and procedure of the study as well as a consent form. Only children whose parents had returned a completed form were allowed to participate in the study. Each child was asked at the beginning of their session if they would like to participate. University participants were also given an information sheet and consent form indicating the purpose and procedure of the study. Children were given stickers for participating and adults were given course credit.

Materials and Procedure

Prior to participation, informed consent was obtained from all individual participants included in the study. Adults went on a short walk in and around a building on the university campus and children went on a short walk within the grounds of their preschool. Participants were not told about the purpose of the walk or what they would be doing after the walk. In a quiet room at the university campus and at the preschools, the experimenter sat directly opposite participants and maintained eye contact throughout participants' descriptions. Adults were allocated to either the detail condition or the description condition. Adults in the detail condition were asked, "can you now describe for me the path that we took at the beginning of the session, in as much detail as possible, as if you're describing it to someone who hasn't taken the path but will be taking the path". Adults in the describe condition and children were asked, "can you tell me everything you remember about the walk we took outside?".

Participants were also asked to recall a route that they take regularly. Adults in the detail condition were asked, "can you tell me about the path that you take from home to university as if you're describing it to someone who hasn't taken the path but will be taking the path". Adults in the describe condition were asked, "can you tell me about a walk that you go on from home to university?". Children were asked, "can you tell me about a walk that you go on from home to a park?". Initially, the instructions presented to adult participants in the detail condition were piloted on 12 children to ensure the wording of instructions was appropriate for preschoolers. The instructions regarding detailed description of routes, however, failed to elicit a response from the children. As a result, the wording of instructions for preschoolers was revised to be age appropriate. If any participant took too long before continuing to give the description, the experimenter said, "and where did you/ we go after that?" and/ or "did you/ we go anywhere else?". There are no reasons to expect differences between the two tasks (routes: familiar and unfamiliar). Both tasks were used to establish a richer data set, with greater scope for participants to produce a variety of gestures and speech phrases. The order of route recall was counterbalanced between participants.

Participants' spontaneous actions were of interest, therefore, specific instructions regarding gesturing were explicitly avoided. As the participants' verbal route descriptions and accompanying gestures were of interest, no measure of correct recall was included. No directional feedback or confirmation was provided by the experimenter. Responses were videotaped for later analysis. The entire procedure took 10-15 minutes per participant, completed in a single session.

Coding

Speech was transcribed verbatim, including filled pauses (e.g., “ummm”) and hesitations. Speech content was divided into propositions (i.e., speech phrases) following Daniel et al., (2009). Speech phrases were minimal information units combining a predicate and one or two arguments. For example, “we turned left out of the building - right out of the building - I’m really bad at my lefts and rights”, was divided into a succession of statements: “we turned left out of the building”; “right out of the building”; “I’m really bad at my lefts and rights”. Propositions were then classified according to five categories outlined by Daniel et al., (2009). Three additional categories (movements with description, location and movement with description, and cardinal directions) were included to capture the descriptive and cardinal information conveyed by participants during route direction communication reported by Allen (2000) and Ward, Newcombe, and Overton (1986). See Table 1 for a full list of phrase categories and their associated characteristics.

Table 1

Phrase Categories and Characteristics

Category	**Characteristics**
Location no description	A proposition where a location is mentioned without reference to any movement to be executed, e.g., “the garden is on the right”.
Location with description	Propositions including both the location and a description of its characteristic features without prescription of movement, e.g., “the road is very bendy”. Here the location is “the road” and the description is “very bendy”.
Movement no description	A proposition involving the prescription of movement without reference to a location, e.g., “turn left”.
Movement with description	A proposition including both the movement to be taken and a description of its characteristic features without reference to a location, e.g., “walk quickly to the right”. Here the movement is to “walk to the right” and the description is “quickly”.
Location and Movement no description	When a proposition includes a prescription of movement with reference to a location, e.g., “go straight to the lights”. Here the location is “the lights” and the movement is “go straight”.
Location and Movement with description	Where the proposition includes a prescription of movement with reference to a location and includes a description of characteristic features of one or both, e.g., “go up the steep incline halfway down the road”. Here the location is “halfway down the road”, the movement is “go up”, and the description is “steep incline”.
Cardinal Directions	Statements describing cardinal directions, e.g., “south is that way”.
Comments	Statements referring to the route without providing relevant information, e.g., “the air conditioner keeps it cool”.

Gestures were segmented into individual gestures and only included hand and arm movements using the format described in McNeill (1992). Individual gestures were described in terms of hand shape, placement and motion, including identifying the speech content they accompanied. Incidental and irrelevant hand movements, e.g., fiddling with hair, were not coded. Gestures were classified according to the following categories outlined by McNeill (1992), Alibali et al., (2000), Cassell et al., (2007) and Thompson, Driscoll, and Markson (1998). See Table 2 for a full list of each gesture type and associated characteristics.

Table 2

Gesture Categories and Characteristics

Category	**Characteristics**
Iconic	Depicts a concrete image of an event or object, e.g., "We exited the automatic doors", *palms facing chest hands move from periphery to center then back to the periphery*.
Deictic	Pointing movements, typically performed with an extended finger, however, any body part can be used, e.g., "Turn right again", *right hand fingers extended forward, moves in a chop action to point right*.
Metaphoric	Depicts a concrete image of an abstract concept, e.g., "there's kind of two potential options", *cupped palms facing up, hands alternate moving up and down.*
Beat	small, biphasic hand movements containing no apparent semantic meaning, e.g., "and then you walk into Uni", *palms down, hands move up down.*
Iconic-Deictic	simultaneously convey an event and a location, thereby belonging in two categories, e.g., "walk along the edge of the building", *left hand palm right, fingers pointing forward, edge resting on the table; right hand pointing down moves forward next to left hand.* Here, the left hand depicts the building (iconic), while the right hand indicates movement direction (deictic).

Note. Underlined words indicate the point at which the participant gestured.

Finally, the redundancy of each gesture was assessed based on the information expressed in gesture and the information expressed in speech (Alibali et al., 2000). Binary categorization of a gesture as either redundant or non-redundant, however, serves only to simplify naming and does not designate “more” or “less” the extent of additional information conveyed by a gesture (Gregory, 2004). Gestures differ in the extent to which they communicate additional information, and as such, these differences are not picked up by the commonly used practice of binary coding, placing gestures into redundant and non-redundant categories (Beattie & Shovelton, 1999). In order to maximize the information obtained about the extent a gesture conveys information consistent with or beyond speech content, a summative/ Likert redundancy rating scale was developed for measurement purposes (Gregory, 2004). Gestures were rated according to the degree to which they contained information not expressed in speech content on a scale from 1 (*Redundant*, e.g., “go straight along the wide path” accompanied by a gesture pointing forward, i.e., information about direction present in speech) to 9 (*Non-redundant*, e.g., “follow the road” accompanied by a gesture indicating the road turns to the right, i.e., novel information about the direction of the road not present in speech). A rating of 5 indicates that the gesture conveys some information present in speech and some novel information (e.g., “turn at the end of the corridor” accompanied by a gesture indicating a turn to the right, conveying turning information present in speech, while also conveying novel information that the direction of the turn is to the right).

Reliability

A second coder independently coded a random sample of the spoken and gesture transcripts (i.e., 25%, 27 out of 106 transcripts). Inter-rater reliability was evaluated through single-rater intraclass correlations (ICCs), with a consistency model. When comparative judgements are made about objects of measurement, a consistency model takes the ratings of two or more judges and through an additive transformation serves to equate them to determine the extent of agreement between them (McGraw & Wong, 1996; Shrout & Fleiss, 1979). Using a consistency definition, an ICC value of 1.00 reflects perfect agreement while ICC values closer to 0.00 reflect imperfect agreement (i.e., a large discrepancy between judges' ratings; McGraw & Wong, 1996). For speech coding, intraclass correlations were obtained for phrases without description ($ICC = .861$, $p < .001$), and phrases with description ($ICC = .978$, $p < .001$; see below for the collapsing of speech categories). For gesture coding, intraclass correlations were obtained for iconic gesture ($ICC = .876$, $p < .001$), deictic gesture ($ICC = .983$, $p < .001$), metaphoric gesture ($ICC = .614$, $p < .001$), beat gesture ($ICC = .746$, $p = .001$), and iconic-deictic gesture ($ICC = .692$, $p < .001$). An intraclass correlation was similarly obtained for the redundancy rating scale for gestures ($ICC = .798$, $p < .001$).

Results

Analysis Plan

Descriptive statistics were used to assess the distribution of each dependent variable. Multilevel Modelling was then used for analyses due to the nested nature of the data, with speech phrases and gestures being nested within participants (MLM; Peugh, 2010). Naturally nested data structures, such as children within classrooms, or repeated observations within participants as in the current study, violate the assumption of independence of observations needed for traditional statistical analyses (e.g., Analysis of Variance; Peugh, 2010). Ignoring this violation results in biased parameter estimates and may inflate error rates. Here, participants produced different numbers of speech phrases, precluding the use of traditional repeated measures analyses. For the current analyses, therefore, individual speech phrases and gestures were treated as the Level 1 unit, with participants as the Level 2 unit. Where appropriate, follow up tests of simple effects were Bonferroni adjusted to control the family-wise error rate at alpha = .05. Where appropriate, Cohen's *d* has been reported as a measure of effect size. There are no effect sizes for multinomial logistic multilevel model main effects and interactions at this time, however, odds ratios for simple effects are reported. Individuals who talk for longer have greater opportunities to produce gesture, therefore, total number of words produced was entered as a covariate to assess the differences in gesture production between adults and children in relation to the number of words produced during recall.

Preliminary Analyses

A preliminary analysis was conducted to determine which distribution was appropriate for each analysis. Given the skew or categorical nature of some variables, a negative binomial, a multinomial, and normal distribution was applied where appropriate. Participants produced iconic (children n=95, adults n=231), deictic (children n=91, adults n=1710), iconic-deictic (children n=19, adults n=217), metaphoric (children n=18, adults n=40), and beat (children n=6, adults n=168) gestures (children N=229, adults N=2366). Few metaphoric or beat gestures were produced by participants during recall. They were therefore excluded from inferential analyses but are included in the descriptive statistics below. The phrase types "comment" and "cardinal directions" were similarly excluded due to low production rates by both adults and children. Phrases were then converted into a binary variable indicating phrases with or without description. Phrases and gestures were pooled across the two routes recalled, as no significant main effects or interactions for route type were found. Similarly, no effects of gender were found for any analyses, and gender was excluded in the analyses below.

Main Analyses

Frequency of each type of gesture at recall. Descriptive statistics were used to examine the types of gestures produced by adults and children at recall. Both children and adults primarily produced iconic, deictic and iconic-deictic gestures (see Figure 1). The mean phrase to gesture ratio was 3.34 for children, such that gestures accompanied 33.4% of phrases. For adults asked to convey detailed directions, the phrase to gesture ratio was 2.34, such that gestures accompanied 23.4% of phrases. For adults asked to describe directions, the phrase to gesture ratio was 3.42, such that gestures accompanied 34.2% of phrases.

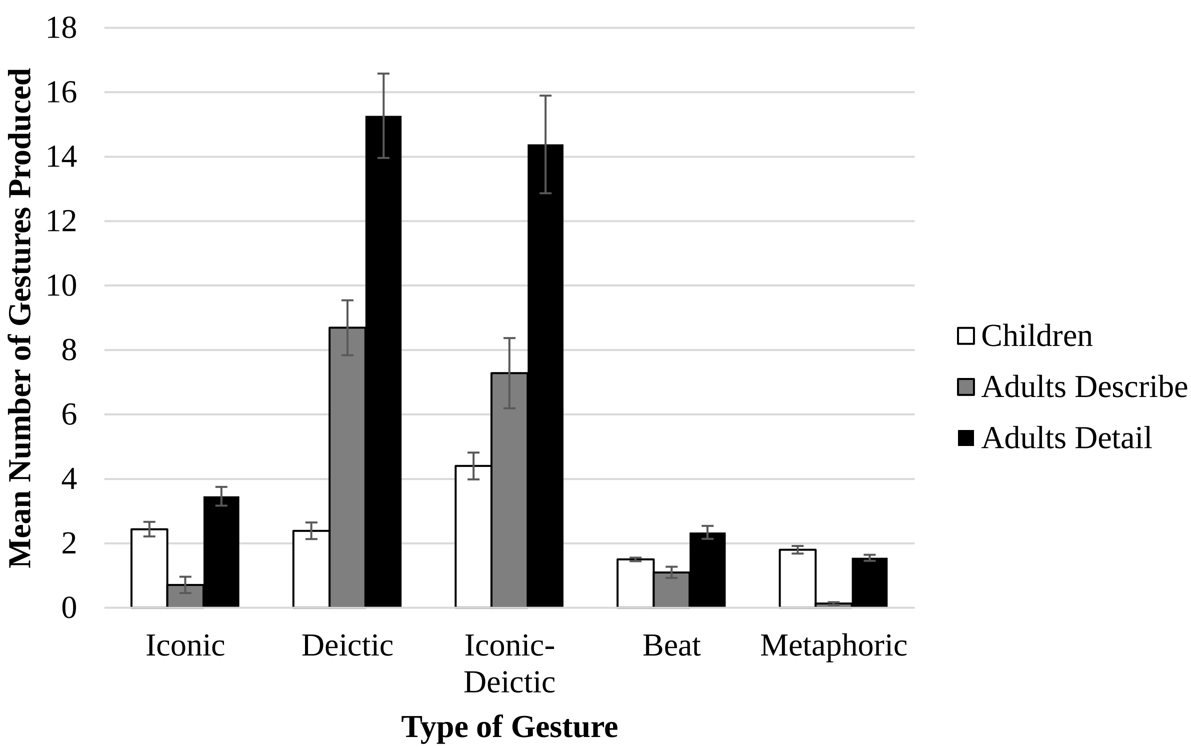

Fig. 1 Mean number of each type of gesture produced by children and adults across the recall of both routes. Error bars represent standard errors. Note: N=106, 31 children, 36 adults describe, and 39 adults detail.

Differences in gesture production at recall. A Negative Binomial Multilevel Model analysis with 2 predictors, group (child, adult describe, adult detail), and type of gesture (iconic, deictic, iconic-deictic) was carried out to examine differences in the rate of production of gesture at route direction recall between children and adults and between the two adult conditions. The total number of words produced by each participant was entered as a covariate to control for differences in the amount of speech produced by children and adults. Group significantly predicted the number of gestures produced at recall, $F(2,626) = 5.59$, $p = .004$. Examination of simple effects revealed that adults produced more gestures than children, whether adults in the description condition ($F(1,626) = 8.83$, $p = .003$, $d = .70$) or adults in the detail condition ($F(1,626) = 9.02$, $p = .003$, $d = .76$). There was no difference in the number of gestures produced between adults in the describe condition and adults in the detail condition ($F(1,626) = 0.26$, $p = .610$, $d = .12$). There was a main effect of type of gesture, $F(2,626) = 71.92$, $p < .001$, such that more deictic gestures ($F(1,626) = 69.17$, $p < .001$, $d = .82$), and iconic-deictic gestures ($F(1,626) = 76.35$, $p < .001$, $d = .97$) were produced than iconic gestures, but no difference in the number of deictic and iconic-deictic gestures produced ($F(1,626) = .16$, $p = .686$, $d = .04$).

There was a significant interaction between age group and type of gesture, $F(4,626) = 13.74$, $p < .001$. Simple effects analysis revealed that children produced more iconic gestures than adults in the describe condition ($F(1,626) = 9.33$, $p = .002$, $d = .62$), however, adults in the describe condition produced more deictic ($F(1,626) = 28.47$, $p < .001$, $d = .85$) and iconic-deictic gestures ($F(1,626) = 9.45$, $p = .002$, $d = .63$) than children. There was no difference in the number of iconic ($F(1,626) = 3.67$, $p = .056$, $d = .45$) and iconic-deictic gestures ($F(1,626) = 6.01$, $p = .015$, $d = .41$) produced between children and adults in the detail condition. Adults in the detail condition produced significantly more deictic gestures ($F(1,626) = 25.44$, $p < .001$, $d =$

.79) than children. There was no significant difference between adults in the describe condition and adults in the detail conditionin the production of iconic, deictic and iconic-deictic gestures (all *p*s > . 005). (see Figure 1).

The informational relationship between speech and gesture. A Linear Multilevel Model analysis with 2 predictors, group (child, adult describe, adult detail) and type of phrase (with description, without description), was carried out to examine the amount of additional information gesture conveyed beyond the associated phrase content, as measured by the redundancy rating scale. Group significantly predicted the redundancy of gestures produced at recall ($F(2,2298) = 3.43$, $p = .033$). Examination of simple effects revealed that children's gestures depicted information beyond speech content to a greater extent than did adults in the describe condition ($F(1,2298) = 6.85$, $p = .009$, $d = .65$). There was no significant difference between children and adults in the detail condition ($F(1,2298) = 2.54$, $p = .111$, $d = .39$), or between adults in the describe condition and adults in the detail condition ($F(1,2298) = 1.86$, $p = .172$, $d = .32$). There was a main effect of type of phrase ($F(1,2298) = 6.85$, $p = .009$, $d = .06$), such that gestures accompanying phrases with description conveying information beyond speech content to a greater extent than for phrases without description.

There was a significant two-way interaction between group and type of phrase ($F(2,2298) = 4.85$, $p = .008$). Simple effects analysis revealed that children's gestures depicted information beyond speech content to a greater extent than did those of adults in the describe condition for phrases without description ($F(1,2298) = 19.80$, $p < .001$, $d = 1.13$). For phrases with description there was no significant difference between children and adults in the describe condition ($F(1,2298) = .06$, $p = .803$, $d = .06$). For phrases without description, children's gestures depicted information beyond speech content to a greater extent than did adults in the detail condition

(*F*(1,2298) = 8.56, *p* = .003, *d* = .74). For phrases with description, there was no significant difference between adults and children (*F*(1,2298) = 0.02, *p* = .887, *d* = .04; see Figure 2). There was no significant difference between adults in the describe condition and adults in the detail condition for both phrases without description (*F*(1,2298) = 5.30, *p* = .021, *d* = .53), and phrases with description (*F*(1,2298) = .20, *p* = .656, *d* = .10).

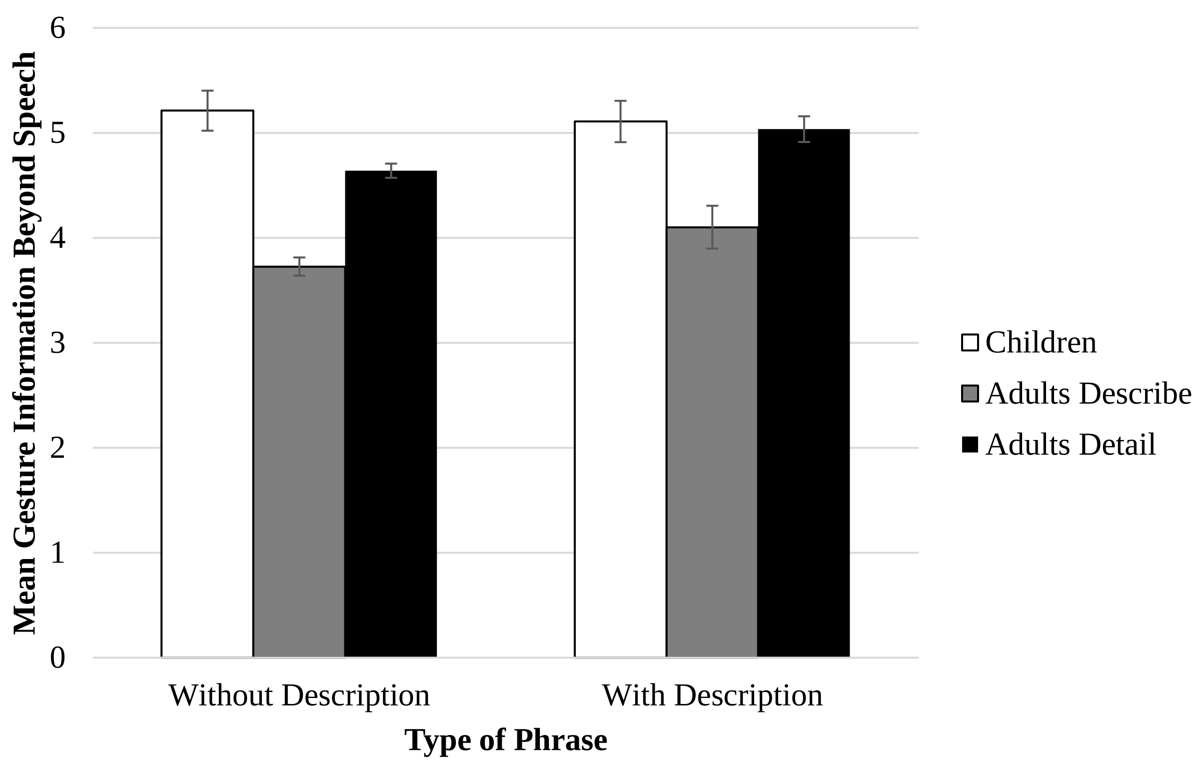

Fig. 2 Mean additional information conveyed in gesture beyond speech content by children and adults for each type of phrase. Error bars represent standard errors. Note: N=106, 31 children, 36 adults describe, and 39 adults detail.

The relationship between types of gesture and phrase content. A Multinomial Logistic Multilevel Model[1] analysis with 2 predictors, group (child, adult describe, adult detail)

[1] There are no effect sizes for multinomial logistic multilevel model main effects and interactions at this time, however odds ratios for simple effects are reported.

and type of phrase (with description, without description) was carried out to examine the relationship between the types of gesture produced (iconic, deictic, iconic-deictic) and phrase type and group. There was a main effect of group, $F(2, 2292) = 16.65$, $p < .001$, and a main effect of type of phrase, $F(1, 2292) = 39.94$, $p < .001$.

There was a significant two-way interaction between group and type of phrase, $F(2, 2292) = 5.11$, $p < .001$. Examination of simple effects revealed that children were less likely to produce deictic than iconic gestures for phrases with description than phrases without description (OR = 0.15, 95% CI [.06, .20], $p < .001$), and less likely to produce iconic-deictic than iconic gestures for phrases with description than phrases without description (OR = 0.15, 95% CI [.05, .49], $p = .002$) than are adults in the describe condition. There was no effect of type of phrase on the production of deictic compared with iconic-deictic gestures ($p > .05$; see Figure 3).

Adults in the describe condition, on the other hand, were more likely to produce deictic than iconic-deictic gestures for phrases without description than phrases with description (OR = 3.26, 95% CI [1.72, 6.19], $p < .001$), and more likely to produce deictic than iconic gestures for phrases without description than phrases with description (OR = 5.40, 95% CI [2.79, 10.48], $p < .001$) than are children. There was no effect of type of phrase on the production of iconic-deictic compared with iconic gestures ($p > .05$). This pattern of results was replicated when comparing the relationship between gesture types and types of phrase between children and adults in the detail condition.

Adults in the describe condition were more likely to produce deictic than iconic-deictic gestures for phrases without description than phrases with description (OR = 3.25, 95% CI [1.71, 6.17], $p < .001$), and more likely to produce deictic than iconic gestures for phrases without description than phrases with description (OR = 5.45, 95% CI [2.81, 10.55], $p < .001$) than were adults in the detail condition. There was no effect of type of phrase on the production of iconic-deictic compared with iconic gestures (*p* > .05).

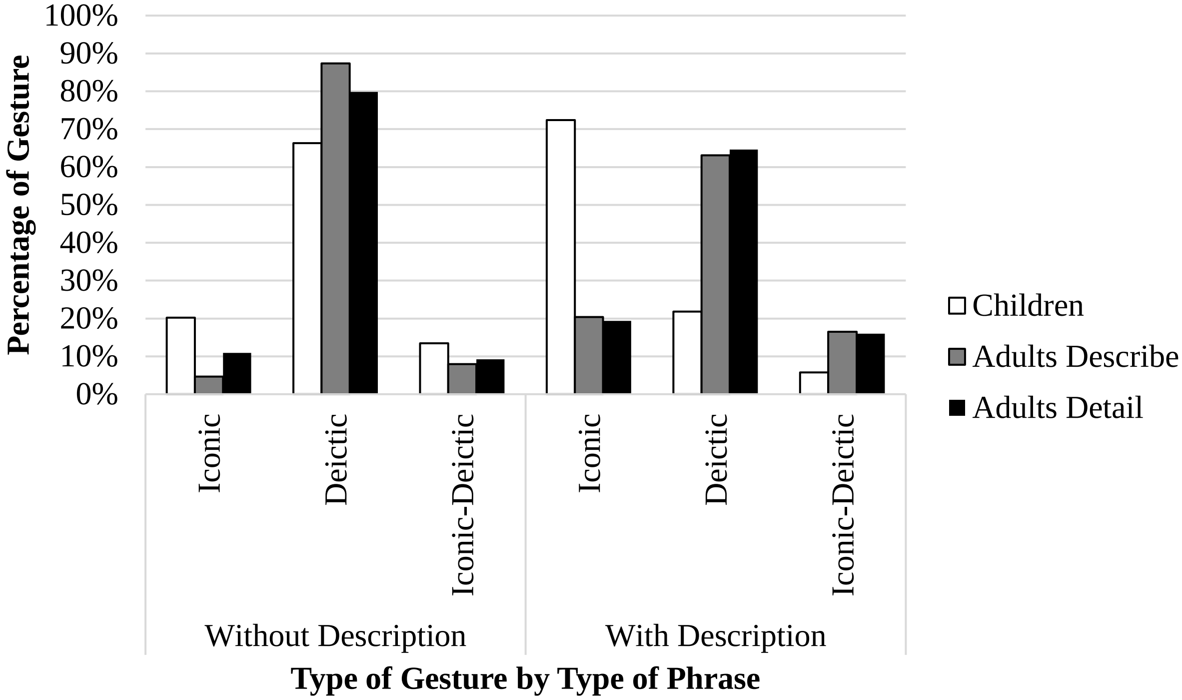

Fig. 3 Percentages of each gesture type produced by children and adults for each type of phrase. Note: N=106, 31 children, 36 adults describe, and 39 adults detail.

Discussion

Here, we captured some of the complex role that gesture plays in relaying route direction information by preschool children and adults. While not all phrases were accompanied by gesture, most participants produced a range of gestures when conveying route directions from memory. Three kinds of gestures dominated however, namely iconic, deictic, and iconic-deictic gestures. In relation to the number of gestures produced during recall, adults produced more gestures than children, with the biggest difference found in the production of deictic and iconic-deictic gestures.

Differences in gesture production at recall. When describing route directions, children produced more iconic gestures than adults but adults produced more deictic and iconic-deictic gestures than children. One possibility is that children's greater production of iconic gestures reflects developmental differences in the conceptualization of space. That is, it may be that children's cognitive limitations in both theory of mind/ spatial perspective taking, as well as in language (e.g., the meaning of the words left and right), result in a more concrete conceptualization of space that is reflected in the greater production of enacting gestures. Adults, with a wider vocabulary and greater capacity for spatial perspective taking, generate a more abstract mental representation of space, reflected in the greater production of pointing gestures. Developmental differences in the production of gestures, therefore, imply that processing environmental information and thinking about space changes as language and cognitive capacity increase with age.

Given that task purpose influences the processing and subsequent recall of environmental information, it is important to examine whether developmental differences in gesture and speech production hold when adults are given task instructions in language more appropriate to adults (Taylor et al., 1997). Adults asked to convey route directions in detail continued to produce more deictic gestures than children, however, adults asked to convey the route in detail and children produced similar amounts of iconic and iconic-deictic gestures. In other words, the developmental difference in deictic gesture production holds when adults are given the same task instructions as children and when given task instructions in language more appropriate to adults. The developmental difference in gesture production is further supported by the finding that adults asked to convey the route in detail produced similar amounts of each type of gesture as adults asked to describe the route. For adults, changing task instructions from describing the route to conveying it so that someone can follow the route based on their route directions does not change how adults use gesture when communicating about space. Taken together, these findings provide further evidence of developmental differences in gesture production during the communication of spatial information.

The informational relationship between speech and gesture. Given that listeners derive the semantic meaning of gestures from the words and phrases they accompany, it is important to view the differences in adult and child gesture production within the context of the phrases they accompany (Blades & Medlicott, 1992; Capirci & Volterra, 2008; Tversky, 2011). Children's gestures depicted information beyond speech content to a greater extent than did adults' for phrases with and without description. For example, a child accompanied the phrase "I went over there" with a gesture *pointing to the right,* while an adult produced the same gesture accompanying the phrase "we turned right". This suggests that children may compensate for limitations in their verbal capacity by using their hands to extend the meaning of their verbal output.

While children's gestures depicted a similar amount of information beyond speech for both phrases with and without description, when phrases did not include a description, children's gestures depicted information beyond speech content to a greater extent than did those of adults asked to convey detailed directions. It is possible that compared with children, adults' language capacity to convey detailed route directions reduces the need for gestures to accompany speech when description is not included in the phrase content. Furthermore, adults asked to convey detailed directions produced gestures which depicted information beyond speech content to a similar extent as adults asked to describe the route regardless of the type of phrase. In other words, the request for detailed route directions elicits gestures which extend the information conveyed in speech content to a similar extent as instructions to describe a path through the environment. These findings are important because they reflect qualitative differences in gesture production as a function of development and qualitative similarities as a function of task purpose.

The relationship between types of gesture and phrase content. Closer examination of the types of gestures accompanying phrases with and without description revealed that children conveyed direction information (deictic) with their hands when phrases did not include descriptive content and depicted concrete images of referents (iconic) when phrases did include a description. In contrast, adults used their hands to convey direction information for phrases both with and without description regardless of the spatial task instructions. These results suggest that while adults use their hands to convey direction information, children use their hands to enrich their verbal description of space and to convey direction information when not describing space. In this way, children use gestures to convey environmental characteristics of movements and locations required for successful route completion, which may be beyond the limitations of their vocabulary. The similarity in adults' production of different types of gestures accompanying phrases with and without description for the different task purposes suggests that the purpose of the task does not change the way we communicate about space.

In context. To this point, the frequency, type and timing of gestures accompanying route directions remained the focus of studies examining adult and early childhood spatial communication (Allen, 2003; Sekine, 2009). Allen (2003) reported that adults primarily produced deictic and iconic gestures when conveying route directions from memory, with only one other study reporting that the visual characteristics of gestures correspond to the spatial features of spoken referents (Cassell et al., 2007). Looking at preschool aged children, 4 year olds, not yet able to give coherent and accurate route directions, produced proportionally more gestures than 6 year olds (Sekine, 2009). Together with the current study, these findings suggest that gesture provides a valuable resource for information about a child's mental representations of environmental space, particularly when they perhaps do not have the verbal resources to provide as detailed descriptions as do adults.

Task instructions and purpose also influence the way we think and communicate information (Emmorey et al., 2000; Galati & Brennan, 2013; Gelman, Ware, Manczak & Graham, 2013). To date, the impact of task instructions on spatial communication, in particular, gesture production has been somewhat overlooked. There is some evidence that speakers adapt their gestures as a function of the perceived knowledge state of their listener (Galati & Brennan, 2013; Kang, Tversky, & Black, 2015). For example, when explaining a topic to a novice, speakers first establish a common knowledge base, relying on a paper diagram as well as producing gestural diagrams to facilitate communication (Kang et al., 2015). When explaining a topic to an expert, however, speakers begin with and rely on the paper diagram to facilitate communication (Kang et al., 2015). Furthermore, gestures can reflect the spatial perspective taken by the speaker with adults producing gestures in 3D space when communicating about space (route perspective) and gestures along a 2D plane when describing space from a single viewpoint (survey perspective; Emmorey et al., 2000). Similarly, other domains demonstrate that speech content changes as a function of the task purpose, with adults and children aged 5 and 6 years using general language terms in teaching contexts and when in a teacher role than in narrative contexts (Gelman et al., 2013). The influence of test conditions on speech and gesture have been tested with other content, but not for gesture production in relation to speech content, and not for route information. In the current study, the similarity in the ways adults produced gestures and their connection to speech content despite differences in spatial task purpose suggests that the verbal and nonverbal way we communicate about space is qualitatively and quantitatively stable, regardless of how it is elicited.

The function of gesture production when communicating spatial information. At all ages, thinking and communicating takes place within the context of the physical environment and as such, the production of gesture and its function for speakers needs to be understood in that context (Wilson, 2002). In any environment, our ability to process, store, and convey information ultimately depends on our cognitive parameters (Just & Carpenter, 1992). Embodied cognition theory suggests that we use the environment, through the production of gestures, to hold and/ or manipulate information in order to overcome the limitations in our ability to simultaneously process information (e.g., attention and working memory; Wesp et al., 2001; Wilson, 2002). In this way, externalizing or embodying mental representations of our thoughts through the production of gestures during thinking and communication can extend the limitations of our cognitive parameters and thereby facilitate the thinking process (Wilson, 2002).

Despite existing only momentarily in the external environment, gestures ground thought processes and communication in the environment, and in so doing, allows speakers to offload cognitive workload (Tversky, 2011; Wilson, 2002). For adults, producing deictic gestures reduces the overall load on cognitive resources by conveying route elements (e.g., direction of a landmark or movement) through pointing, thereby reducing the workload of the speech production system, making more resources available for concurrent cognitive processes (e.g., memory; Goldin-Meadow et al., 2001; Just & Carpenter, 1992; Wilson, 2002). In other words, producing deictic gestures accompanying spatial route information reduces the resources needed by the speech production process makes more resources available for creating and maintaining spatial mental representations, thereby facilitating route direction communication (Cameron & Xu, 2011). At the same time, by reflecting speakers' mental representations, gestures also provide speakers with feedback on their thought processes (Goldin-Meadow & Alibali, 2013; Madan & Singhal, 2012; Wilson, 2002). In this way, gestures clarify and emphasize aspects of spatial messages during the communication process, helping to maintain mental representations of environments and routes, such as position and movement. As extensive cognitive changes occur during development, the function of gesture may also change.

During early childhood, gestures perform a functional role in the construction of phrases and the expression of meaning as vocabulary develops (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing the iconic gesture: *both hands with fingers pointing down pendulum from left to right*, accompanying the descriptive phrase "there is a big zebra crossing", tells the listener how the child conceptualizes the crossing as a location as well as movement associated with it. In this way, the gestures preschoolers produce provide those around them with insight into the content and extent of their spatial knowledge. On the other hand, adults communicating the same phrase might accompany it with a simple pointing gesture indicating to the listener the location of the crossing in relation to the self. The degree of overlap in the content of gestures and the associated speech phrase suggests that gestures primarily help adults translate ideas into speech and, to a lesser extent reduces the need to translate ideas into speech at all. Conversely, the degree of additional information present in gesture beyond that contained in speech phrases suggests that while children use gestures to transform ideas into speech, gestures are primarily used to reduce the need to translate ideas into speech at all. In the current study, the differences in the ways preschoolers and adults produce gestures and their connection to speech content suggests that the verbal and nonverbal way we communicate about space changes as language and cognition develop.

As well as playing a functional role in the construction of phrases and therefore, the communication of meaning, during development gestures may also facilitate the management and allocation of limited mental resources (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing a gesture enacting climbing a tree to indicate a location, disambiguates it from another location along the route which might be accompanied by a gesture enacting height. In this way, producing iconic gesture provides preschoolers with a means to communicate spatial knowledge beyond the limitations of their current vocabulary and cognitive capacity (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007; Madan & Singhal, 2012; Wilson, 2002). Importantly, this suggests that the embodiment of thought processes through gesture production may have multiple functions for speakers throughout the lifespan which are not mutually exclusive.

Through form, position and movement, gestures function to reference and represent objects in speech, convey space and movement, facilitate cognition, either separately or concurrently through a single gesture (Kok, Bergmann, Cienki, & Kopp, 2016). That is, gesture provides the cognitive system with a stable external physical and visual presence that can provide speakers with a means through which to think and communicate (Pouw, de Nooijer, van Gog, Zwaan & Paas, 2014). Gestures re-represent action in the form of abstracted action, and as such, offloading cognitive work into the environment through abstracted actions is particularly relevant for tasks involving actions (i.e., spatial tasks; Wilson, 2002). As with other tasks, gesture may serve two functions for speakers performing spatial tasks: help speakers translate spatial knowledge/ information into speech and/ or directly communicate spatial location/

movement information, thereby eliminating the need to translate this information into speech (Hostetter & Alibali, 2007; Wilson, 2002).

Limitations and Future Research

It should be noted that the accuracy of verbal recall, as well as the relationship between the form of the gesture and the spatial feature of the entity to which it refers could not be assessed. Existing research suggests that the gestures adults produce relate meaningfully to the visual characteristics of spatial features of the entity to which they refer (Cassell et al., 2007). In this study, children and adults were asked to recall the short walk they were taken on at the beginning of the session, as well as a walk they take regularly. While this method allows us to examine developmental differences in gesture production, gesture redundancy and the relationship between types of gesture and phrase content, it does not allow us to examine the role gestures play in accurate route communication during development. It is possible, that the developmental differences in gesture production found in the current study also extend to developmental differences in the relationship between gesture and accurate route communication, as well as the correspondence between the morphological features of gestures and the visual aspects of referents. Future research could determine whether children's speech and gesture when reporting route direction information is accurate, and whether the morphological features of children's gestures correspond to the visual aspects of referents.

Speakers may change their production of gesture based on their perception of their listeners' needs. While participants were instructed to convey the route directions as they would to a listener who was unfamiliar with the route, it is possible that participants might produce different route descriptions to a novel listener. Future research could investigate the impact of listeners' perceived expertise on speakers' production of gesture. Furthermore, future research should include measures of ethnicity, number of languages spoken, native language, and spatial knowledge.

In order to understand the differences in gesture produced between children and adults, it is important to investigate the related cognitive and language abilities of participants. Future research could include measures of spatial skills (e.g., spatial memory), as well as measures of cognitive skills (e.g., language). Examining the relationship between gesture production during spatial route communication and participants' spatial and language skills will enhance our understanding of the function of gesture in spatial tasks. Continued research into verbal and nonverbal spatial communication, such as an examination of description accuracy, gesture morphological correspondence and spatial and language skills, will prove integral to increasing our understanding of gesture as a way to extend the mind through embodying thought processes.

Language not only enables us to directly communicate what we think about space, but it also shapes how we think about it (Tversky, 2011). Throughout development, our vocabulary for describing space expands as we interact with the world and with others, from single word-gesture utterances as infants, until as adults, our vocabulary allows us to effectively communicate spatial knowledge through words alone (Bates, 1976; Blades & Medlicott, 1992; Capirci & Volterra, 2008; Daniel et al., 2009; Iverson & Goldin-Meadow, 2005; Tversky, 2011). The findings from the current study suggest that preschoolers' spatial knowledge is deeper than that which their limited vocabulary allows them to verbally express. By using gestures to represent visual characteristics and directions, preschoolers can convey the physical qualities of the route and the movements required beyond the limitations of their developing vocabulary. By examining differences between adults' and preschoolers' use of gesture in relation with speech we are able to capture some developmental changes in spatial cognition and language, beyond that which speech alone allows. These differences highlight the need to include measures of gesture when examining cognition and language during development.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Chapter 3. Getting to the Elephants: Gesture and Preschoolers' Comprehension of Route Direction Information

Published as: Austin, E. E., Sweller, N., (2017) Getting to the elephants: gesture and preschoolers' comprehension of route direction information, *Journal of Experimental Child Psychology*, vol. 163, pp. 1-14, https://doi.org/10.1016/j.jecp.2017.05.016.

The present chapter presents my second empirical paper which examines the effect of gestures accompanying spatial route direction information on recall for preschool aged children. As outlined in Chapter 1, one aim of this thesis is to investigate whether gestures accompanying route direction information can enhance recall and successful task performance for young children. This paper achieves this by presenting children with verbal route directions through a zoo themed spatial array and, depending on assigned condition (no gesture, beat gesture, or iconic / deictic gestures), accompanying gestures. This experiment builds on the previous chapter which focused on the production of speech and gesture and how together they communicate spatial information. The results of the study reported in Chapter 2 showed that the gestures preschoolers produced depicted a similar amount of information beyond speech content for both speech phrases with and without description. The study also revealed that children's gestures conveyed information beyond speech content to a greater extent than adults' gestures. The present chapter represents the first attempt in this thesis to show that a speaker's gestures benefit their listeners' encoding and recall of route direction information.

As outlined in Chapter 1, one aim of this thesis is to determine whether, and why, gesture is a useful tool to facilitate listeners' successful spatial task performance, both during language development and adulthood. Previous work has shown that a speaker's gestures can explain differences in listener recall during early childhood in the context of small-scale route direction information (Austin & Sweller, 2014). However, the present study is the first of its kind to explore how gestures accompanying large-scale route direction information can enhance encoding, and therefore, recall of route information and lead to successful route navigation during the preschool years. By manipulating the gestures accompanying large-scale route directions, the study was able to investigate the role of different types of gesture in how preschool aged children encode, retain and subsequently recall spatial information.

This chapter is the first to examine how gestures accompanying spatial information affect listener recall. Chapter 1 proposed that the embodiment of speakers' thought processes through gesture may benefit listeners for multiple reasons which may be interdependent. For instance, during language development gestures may act to disambiguate unfamiliar terms, and thereby indirectly reduce the speech comprehension processing demands, increasing cognitive resources available for other concurrent processes such as memory. Similarly, gestures facilitate the creation of an imagined mental representation of the speaker's message, deepening the processing of the information and reducing the load on concurrent cognitive processes. The rest of this thesis investigates whether gestures accompanying route direction information can enhance the recall and successful task performance for listeners, and this chapter is the first attempt to do so for young children. Establishing the effect of gesture on recall and task performance during early childhood is important for enhancing our understanding of language and memory processes during development. In doing so, this chapter addresses the second aim of the thesis.

Student Statement of Contributions

I was the major contributor to this co-authored paper. I was responsible for developing the conceptual argument and study design, and did this in consultation with my primary supervisor, Naomi Sweller. I also collected all data and conducted the statistical analyses with input and advice from Naomi Sweller. I drafted the first version of the manuscript, and Naomi Sweller provided feedback and suggestions on multiple versions of the manuscript.

As outlined in Chapter 1, this paper has been accepted for publication by the *Journal of Experimental Child Psychology*. The full reference is:

Austin, E. E., & Sweller, N. (2017). Getting to the elephants: Gesture and preschoolers' comprehension of route direction information. *Journal of Experimental Child Psychology*, *163*, 1-14. doi: 10.1016/j.jecp.2017.05.016

Getting to the Elephants: Gesture and Preschoolers' Comprehension of Route Direction Information

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Word count: 7,422

Submission date: 21st September 2016

Resubmission date: 10th February 2017

Resubmission date: 25th May 2017

Resubmission date: 30th May 2017

Abstract

During early childhood, children find spatial tasks such as following novel route directions challenging. Spatial tasks place demands on multiple cognitive processes, including language comprehension and memory, at a time in development when resources are limited. As such, gestures accompanying route directions may aid comprehension and facilitate task performance by scaffolding cognitive processes including language and memory processing. This study examined the effect of presenting gesture during encoding on spatial task performance in early childhood. Three- to five-year-olds were presented with verbal route directions through a zoo themed spatial array and, depending on assigned condition (no gesture, beat gesture, or iconic/ deictic gestures), accompanying gestures. Children presented with verbal route directions accompanied by a combination of iconic (pantomime) and deictic (pointing) gestures verbally recalled more than children presented with beat gestures (rhythmic hand movements) or no gestures accompanying the route directions. The presence of gesture accompanying route directions similarly influenced physical route navigation, such that children presented with gesture (beat, pantomime and pointing) navigated the route more accurately than children presented with no gestures. Across all gesture conditions location information (e.g., the penguin pond) was recalled more than movement information (e.g., go around), and descriptive information (e.g., bright red). These findings suggest that speakers' gestures accompanying spatial task information influences listeners' recall and task performance.

Keywords: gesture, encoding, spatial, listener, recall, preschoolers

Getting to the Elephants: Gesture and Preschoolers' Comprehension of Route Direction Information

Nonverbal behaviours (i.e., gesture) offer a way for young children to convey and comprehend information beyond their current vocabulary (e.g., spatial information; McNeil, Alibali, & Evans, 2000; Morford & Goldin-Meadow, 1992; So, Sim Chen-Hui, & Low Wei-Shan, 2012; Thompson & Massaro, 1994). Although children differ in word learning abilities and language background (i.e., exposure to one or more languages on a regular basis), language and gesture proficiency typically increase throughout childhood to form a single integrated communication system (Adams, Bourke, & Willis, 1999; Capirci & Volterra, 2008; Goldin-Meadow, 1998; Menyuk, 1964; O'Reilly, 1995; Rowe, Silverman, & Mullan, 2013; Sekine, 2009). If gestures offer a way for young children to convey and comprehend spoken messages, then it is important to examine the influence of presenting different types of gestures accompanying a spoken message on task performance.

Types of Gesture

Gestures can reflect real-world objects and communicate some aspects of thought more effectively than words (Cameron & Xu, 2011; Tversky, 2011; Church, Garber, & Rogalski, 2007; Kendon, 1972, 2004; McNeill, 1992). For example, iconic gestures, such as pantomiming the way a dog runs, can convey complex movement characteristics through size and hand shape (Cassell, Kopp, Tepper, Ferriman, & Striegnitz, 2007). Pointing gestures, also called deictic gestures, convey position, movement and directional information to listeners (Cassell et al., 2007). Iconic-deictic gestures combine aspects of both iconic and deictic gestures, such that hand shape and trajectory depict concrete referent characteristics as well as direction or movement information within the same gesture (Cassell et al., 2007). For example, pantomiming a steep downward sloping road that curves accompanying dialogue about travel conveys concrete path characteristics as well as movement information. Metaphoric gestures accompany explanations of abstract concepts, for example, pantomiming “give and take” accompanying dialogue about relationships conveys abstract concept characteristics (Allen, 2003; McNeill, 1992). Conversely, beat gestures are simple rhythmic hand movements which go along with the rhythm of speech and contain no apparent semantic content but may indicate other communicative aspects such as emphasis (Allen, 2003; McNeill, 1992). The integration of speech and gesture enriches communication and grounds language and thought processes in the environment (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Hostetter & Alibali, 2008; Tversky, 2011).

The grounding of language in our sensory experience through gesture suggests two possible pathways whereby gesture might benefit listeners (Hostetter & Alibali, 2008). Gestures accompanying spoken messages provide young listeners with a scaffold for language learning during development by illustrating concepts, conveying additional information, and providing additional cues (Sauter, Uttal, Alman, Goldin-Meadow, & Levine, 2012). As such, speakers’ gestures may make a greater contribution to listener comprehension for complex, ambiguous or challenging spoken messages relative to listeners’ language skills (Alibali & Hostetter, 2010; McNeil et al., 2000; Morford & Goldin-Meadow, 1992). Therefore, during language development, when vocabulary and adult-like language skills have not yet been achieved, the presence of gesture at encoding of spoken messages may act to disambiguate unfamiliar or novel terms used by speakers. Indirectly, these gestures may reduce the information processing demand of language comprehension, thereby increasing cognitive resources available for other processes including memory (Cameron & Xu, 2011).

In addition, embodied cognition suggests that processing information conveyed in speech and gesture activates the same perceptual and motor states involved in gesture production, thereby creating a simulation or mental representation of the speaker's message (Alibali & Hostetter, 2010). This activation reduces the information processing demands of memory by serving as an elaborate encoding strategy (Just & Carpenter, 1992; Madan & Singhal, 2012). Messages accompanied by gestures are processed through verbal, visual and motor modalities, leaving a rich trace in memory and as a result are remembered better than information processed more shallowly through a verbal only modality (Craik & Lockhart, 1972; Madan & Singhal, 2012; Tellier, 2008). The amount of activation available and consequently the depth of processing influences the resources available to transient processing and storage demands of tasks (Just & Carpenter, 1992). Speakers' gestures may benefit young listeners for multiple reasons which may be interdependent. Consistent with this idea, research suggests that young children benefit most when gestures accompany instructions for complex or challenging activities relative to skill (e.g.,a block selection task; McNeil et al., 2000; Morford & Goldin-Meadow, 1992; Sassenberg & Van Der Meer, 2010; Sauter et al., 2012). One such challenging activity is communication of spatial information.

The Role of Gesture in Spatial Communication

Children encounter spatial information in the form of spoken route directions as a part of everyday life (Ehrlich, Levine, & Goldin-Meadow, 2006; Sekine, 2009). Spoken route directions involve a series of locations (e.g., the kennel), movements (e.g., go around) and descriptions (e.g., it is really small) designed to enable travel from A to B in an unfamiliar environment (Cassell et al., 2007). Without the benefit of previous experiences moving through the environment, imagining a mental model of spoken route directions places considerable demands on listeners' comprehension and memory (Allen, 2000). As gestures re-represent spatial information in the form of actions, they may as a result be particularly beneficial for listeners when they accompany spatial messages such as spoken route descriptions.

To date, only one study has examined the effect of speakers' gestures accompanying route descriptions for listeners across ages (Austin & Sweller, 2014). Adults and children aged 4 to 5 years were presented with spoken route directions through a small-scale spatial array accompanied by either no gestures, beat gestures, or a combination of iconic, deictic, beat and metaphoric gestures. Children, but not adults, verbally recalled more of the route when gestures (beat or combined) accompanied the spoken route directions compared with no accompanying gestures. For children, the combination of gestures enhanced recall of spatial location terms but not movement terms. This finding suggests that for young listeners, the gestures speakers produce enhance small-scale route direction comprehension and recall.

However, the study by Austin and Sweller (2014) does not account for the role of gesture in spatial communication at different scales of space (i.e., when the spatial environment cannot be viewed from a single viewpoint). For example, comprehending and recalling information about a large-scale environment that cannot be viewed from a single viewpoint (e.g., navigating through a school where locations are larger than the individual) places greater demands on cognitive resources than small scale environment information, which can be viewed from a single viewpoint (e.g., desktop; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Montello, 1993). If a speaker's gesture enhances comprehension and recall of small-scale spatial information for young children, then it is important to examine whether these cognitive benefits extend to large-scale spatial information tasks when the cognitive demands are greater.

Examining the role of gesture for young listeners during large-scale spatial tasks will further clarify the role of gesture in scaffolding language comprehension.

Speakers’ gestures vary in communicative value, with some gestures benefiting listeners’ task performance more than others through development. For example, both adults and children aged 4 to 5 years recalled more words accompanied by iconic gestures than no gestures (So et al., 2012). Interestingly, beat gestures aided recall for adults but not children, suggesting that both meaningful and non-meaningful gestures enhance memory for adults, while children may not be sensitive to the emphasizing aspect of beat gestures (So et al., 2012). Similarly, preschoolers presented with a videotaped narrative accompanied by gesture (either iconic, deictic, or beat) recalled more than preschoolers presented with no gestures, with iconic and deictic gestures providing the greatest benefit to recall (Macoun & Sweller, 2016). These studies suggest that across ages, individuals process and integrate information conveyed through speech and gesture. These studies also suggest that during the language learning years, speakers’ gestures which depict concrete actions or objects (i.e., iconic and deictic gestures) enhance listeners’ comprehension, retention and subsequent recall of information to a greater extent than gestures which highlight aspects of speech. Importantly, examining the effects of different types of gesture accompanying spatial information will enhance our understanding of the role of gesture in spatial communication and cognition.

As mentioned previously, adults and children primarily produce deictic, iconic and beat gestures when conveying large-scale route directions (Allen, 2003; Austin & Sweller, in press). Therefore, the language and types of gestures modeled need to simulate those naturally produced by adults and children when conveying spatial information, rather than artificially designed gestures. The gestures modeled in Austin and Sweller (2014) were specifically designed for the stimuli in that study and may not mirror the gestures children and adults typically produce. For instance, Austin and Sweller (2014) modeled an equal number of each type of gesture (i.e., iconic, deictic, metaphoric, and beat), however, metaphoric gestures are rarely produced when adults and children convey route directions (Allen, 2003). Therefore, examining the effect of modeling different types of naturalistic gestures accompanying large-scale route directions will further clarify potential differences between types of gestures in communication for young listeners.

Finally, the developmental trajectory of language and gesture production suggest potential differences between verbal recall and physical route navigation as measures of the effects of gesture. Children often express knowledge/ information through gesture or action that they do not convey in speech (Iverson, 1999; Sekine, 2009). In the context of route direction communication young children convey directional information through pointing gestures when they do not have the language to convey direction (i.e., left/ right; Sekine, 2009). Similarly, blind and sighted children aged between 9 and 18 years were asked to recall routes from memory. Children conveyed direction and location information through gesture more often than speech, while path and landmark information was conveyed through speech more often than gesture (Iverson, 1999), suggesting that across ages, individuals use action and speech to convey spatial knowledge. However, children often perform an action before they can describe the action (Iverson, 1999; Sekine, 2009). As such, measures of both verbal recall and physical route navigation will provide a better understanding of the effect of speakers' gesture on listeners' language and memory processes.

The preschool years are a critical time for language and cognitive development. Gestures accompanying spatial instructions may enhance task performance by altering the load on cognitive resources through perceptual and motor activation and/ or by reducing language processing workload by providing additional comprehension cues for the spoken message. To examine the role of gesture in spatial communication during language development, we examined the effect of presenting gestures at encoding accompanying a spatial route directions message on verbal recall of route directions and on cued recall of route directions (i.e., recall of the route when walking through the spatial environment or following the route directions) for children aged 3 to 5 years. A single large-scale spatial direction task was employed to compare the effects of the presence of gesture (no gesture, beat gesture, or iconic/ deictic gesture) on children's recall of the spatial message. Children were presented with a verbal description of a target path through a large scale scene and, depending on assigned condition, with accompanying gestures.

We aimed to examine whether the effect of beat gesture is comparable to that of a combination of iconic and deictic gestures (iconic/ deictic condition). If gestures accompanying route directions augment listener recall by reducing cognitive load, then we would expect the amount of route recalled verbally and during physical route navigation (cued) to be higher for children presented with route descriptions accompanied by gesture (i.e., beat or iconic/ deictic) compared with children presented with spoken route directions (i.e., no gesture). Similarly, we would expect the amount of route recalled to be higher for children presented with a combination of iconic and deictic gestures (i.e., iconic/ deictic) accompanying the route description than children presented with beat gestures accompanying the spoken message.

Spatial route directions are narratives containing information about locations, movements to be made and descriptive information. Research has found that gestures accompanying small scale route directions enhanced recall for location but not movement information (Austin &

Sweller, 2014). Therefore, we aimed to examine the effect of gestures accompanying large-scale route directions on participant verbal and cued recall of location, movement, and descriptive information contained within the spatial message. We expected the amount of location information recalled to be higher than both movement and descriptive information, and the amount of movement information recalled to be higher in turn than descriptive information, during both verbal recall and when physically navigating the route (cued recall). We expected the amount of location, movement and descriptive information recalled to be higher for children presented with route descriptions accompanied by gesture (i.e., beat or iconic/ deictic) compared with children presented with spoken route directions (i.e., no gesture), during both verbal and cued recall.

Method

Participants

A total of 174 children were recruited from preschools in Sydney, Australia (97 boys and 77 girls, mean age = 4 years 5 months, SD = 4 months, range = 3 years 0 months to 5 years 4 months). Two children were removed from analysis due to failure to provide verbal or gestural responses.

Design and Materials

Participants were presented with two A4 pages containing 18 photographs of objects within the spatial array (e.g., plush toy elephant; See Appendix A). Participants were also presented with a single spatial array constructed from cardboard and plaster to simulate a Zoo environment, adapted from Iverson (1999) and Levinson (1997). The Zoo measured approximately 250 x 300 cm (98.4 x 118.1 inches) and consisted of objects (e.g., trees, rocks) made from cardboard and plaster arranged such that the target path was not obvious. Participants were also presented with a video on a laptop with a screen measuring 28 cm width x 16 cm height (11.3 x 6.4 inches). The actor appeared in the center of the video facing forward (see Figure 1 for snapshots of the appearance and position of the actor).

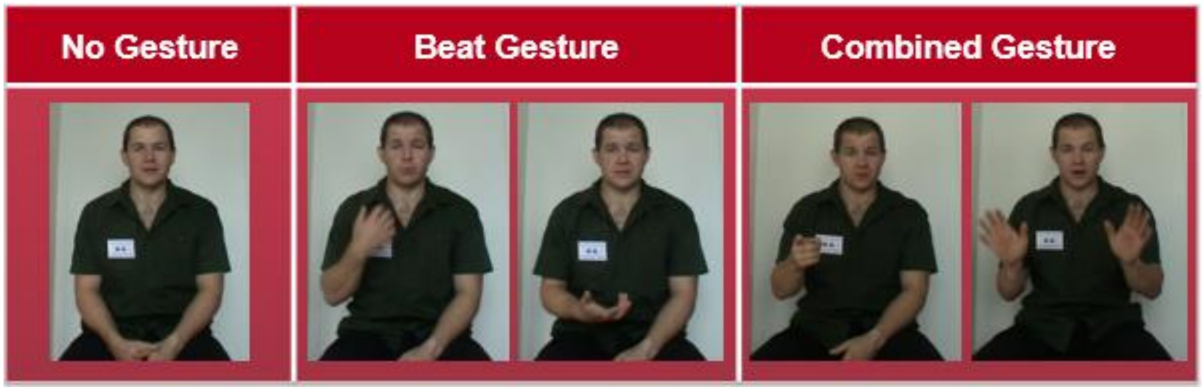

Fig. 1. Snapshots of the position and appearance of actor in the videos.

Participants were randomly allocated to one of three conditions: iconic/ deictic gesture, beat gesture, or no gesture, and presented with a video containing a description of the target path through the zoo spatial array. Participants in the iconic/ deictic gesture condition were presented with a video containing a verbal target path description and 9 accompanying gestures: deictic (n = 7) and iconic (n = 2) based on the frequency and type of gestures produced by adults and preschool aged children when conveying route directions (Austin & Sweller, in press). For example, "Go under the butterfly sign" (deictic gesture: model pointing down, traces a line forward to finish pointing forward as the words "under the butterfly" are verbalized), "go past the penguin pond" (deictic gesture; model points forwards as the words "go past" are verbalized), "go around the bright red bird" (iconic gesture: model imitates wings flapping with hands as the words "bright red bird" are verbalized), "the trees are really tall along here" (iconic gesture: model positions hand with palm facing down above head as the words “trees are really tall” are verbalized).

The video presented to participants in the beat gesture condition consisted of the verbal description and a total of 9 accompanying beat gestures (i.e., simple rhythmic hand movements that contained no apparent semantic information). To enhance the consistency of the model’s performance, prescribed gestures for the iconic/ deictic, and beat gesture conditions were performed at the same set points within the verbal script for each video (see Appendix A for full script and gesture set points). Participants in the no gesture condition were presented with a video containing only the verbal description of the target path while the model’s hands remained still. A single audio track was not used across conditions as the risk of systematic mismatch between audio and visual input (i.e., gestures and mouth movements) outweighed the risk of minor differences in prosody. Therefore, to eliminate any biasing effects of lexical stress (Field, 2013), the model practiced the script several times prior to recording, making sure to stress the movements and locations equally for all videos.

To this end, six videos were created: three practice task videos and three test videos (i.e., one for each gesture condition). The practice task videos were designed to familiarize participants with the task by explaining a series of actions and were identical in language but differed in accompanying gesture. Similarly, the test videos explained a target path through the zoo spatial array and were identical in language but differed in kinds of gesture.

Procedure

To ensure participants’ familiarity with the zoo objects and animals, participants were presented with two A4 pages containing photographs of objects and animals within the zoo spatial array. Each child was asked to name the objects in the photographs in a randomized order. When participants indicated they were unsure or did not know the name of an object or animal the experimenter told them what it was. Participants were then told, "we are going to watch a video of the head zookeeper. He is going to give you some instructions that you have to remember". Participants were then asked, "are you ready to watch and remember everything he says?". Participants were then presented with the practice video describing a series of actions to be performed (e.g., "hop on one foot, turn around") and, depending on assigned condition, the accompanying gestures. On the rare occasion when a participant appeared distracted during the videos, the participant was asked, "Are you listening, [name]?". Participants were then given 90 seconds to complete a coloring-in filler task. On completion of the filler task or after 90 seconds had elapsed (whichever occurred first), participants were asked, "can you tell me everything you remember the zookeeper saying?". Following this, the experimenter told participants "ok, so now we are going to stand up and do everything you remember the zookeeper saying". Participants were then asked "ok, so what do we have to do?". If a participant asked for help or failed to respond, then the experimenter said, "what is one thing you can remember the zookeeper saying" and/ or "what else can you remember him saying?".

Participants were then told, "we are going to watch another video of the head zookeeper. He is going to give you some instructions that you have to remember". Participants were then asked, "are you ready to watch and remember everything he says?". Participants were then presented with the test video describing the target path through the zoo and, depending on assigned condition, the accompanying gestures. Participants were then given another filler task to complete within 90 seconds. Participants were then asked to complete two tasks: a verbal recall task and a cued recall task. For the verbal recall task, the experimenter asked participants, "can you tell me everything you remember the zookeeper saying?". The cued recall task followed this as participants were told, "now we are going to go on a walk through the zoo itself. It's important that you only go where you remember the zookeeper saying". During cued recall, the experimenter walked behind the participant recording the path of movement on a paper map of the zoo. If a participant deviated from the route or did not know where to go next, the experimenter marked the location along the route on the map. Participants who walked off the target path were allowed to progress. If any participant asked for help or failed to respond, the experimenter said, "what can you remember the zookeeper saying?" and/ or "where do you think he went?".

Because participants' spontaneous actions were of interest, specific instructions regarding gesturing at recall were explicitly avoided. No directional feedback or confirmation was provided by the experimenter. During verbal recall, participants' verbal and gestural responses were videotaped and transcribed for later analysis. During cued recall, participants' verbal and gestural responses were noted on the map along with the path they walked. The entire procedure took 10 to 15 minutes per participant, depending on the length of each participant's response. All participants completed the task in one session.

Coding

The speech and gesture produced during verbal recall were transcribed and coded following the procedure used by Austin and Sweller (2014). The speech was transcribed verbatim, including filled pauses (e.g., ummm) and hesitations. A location, movement or description was considered recalled correctly if the speaker's description of the target path included the location, movement or description. For example, the target path contains the phrase, "go around the bright red bird". If the participant said, "go round the bird" the location and the movement were counted as recalled but not the description (i.e., “bright red”) because only the location and movement were mentioned. A location, movement or description term was additionally counted as correct if the participant demonstrated the term through gesture. For example, the target path contains the phrase, “the trees are really tall”. If the participant said, “he said trees” accompanied by a gesture indicating height, then the location and description were counted as correct.

A location, movement or description was not counted as recalled correctly if the speaker’s description of the target path did not include the location, movement or description verbally or through gesture. Movements were not counted as recalled correctly if the movement reported was incorrect. For example, the target path goes under the butterfly sign. If the participant said, “go around the butterfly sign”, the movement was not counted as recalled correctly because the participant incorrectly identified the movement as “around”. The maximum score for location, movement, and description recall were 7, 7 and 3, respectively, with a total recall score out of 17 (see Appendix B for a list of items to be recalled).

During cued recall participants’ navigation through the zoo, gesture and speech were recorded and coded as correct or incorrect. Location and movement items were counted as recalled correctly if the participant mentioned the location either verbally or through gesture and then proceeded on to the next location in serial order. For example, the target path goes under the butterfly sign and then past the penguin's pond. If the participant said, “butterfly sign” and then “the penguins” whilst walking along the target path then the locations (i.e., butterfly sign and penguin pond) and the movements (i.e., go under and go past) were counted as recalled.

If the participant deviated off the target path but mentioned a location verbally then the location but not movement was counted as recalled correctly. For example, the target path includes the phrase "walk forwards for a little bit, go under the butterfly sign", if the participant went left and said "butterfly sign" then the location (i.e., butterfly sign) was counted as correct and the movements (i.e., walk forwards and go under) were counted as incorrect. If the participant indicated a location through gesture (i.e., pointing) they were asked to name the object they were indicating. As participants were not specifically asked to verbalize the path while they walked, recall of descriptive information was not measured during cued recall. As a result, the maximum scores for location and movement recall was 7 and 7 respectively, with a total cued recall score out of 14.

Participant gesture was coded when hand movements that accompanied speech did not serve a functional purpose (e.g., scratching), when direct manipulation of an object occurred (e.g., picking up a zoo object), or when an emblem was displayed (e.g., thumb and pointer finger joined together to mean "okay"). Participant gesture was coded by type and categorized into one of four categories (i.e., beat, deictic, iconic, or metaphoric) according to descriptions outlined by McNeill (1992).

Reliability

Interrater reliability was assessed by having a second coder independently code 25% of the spoken and gesture transcripts as well as the cued recall maps. Reliability was evaluated by obtaining single-rater intraclass correlations (ICCs) assessed through a consistency model. For verbal recall coding, intraclass correlations were obtained for total locations (ICC = 1.000, $p < .001$), total movements (ICC = .985, $p < .001$), total descriptives (ICC = .938, $p < .001$), and total recall (ICC = .923, $p < .001$). For cued recall coding, intraclass correlations were obtained for locations (ICC = .987, $p < .001$), movements (ICC = .986, $p < .001$), and total cued recall (ICC = .989, $p < .001$).

Results

Preliminary Analyses

Given that existing literature has found some evidence of gender differences in the performance of spatial tasks such as mental rotation (Ehrlich et al., 2006), a preliminary analysis was conducted to investigate the effects of gender. Three-way ANOVAs with gesture condition, feature type, and participant gender were carried out for both verbal and cued recall. Both analyses revealed no significant main effect, two- or three-way interactions involving gender for either verbal or cued recall (all ps > .05). Gender was therefore excluded from the main analyses reported below.

Main Analysis

Two mixed design ANOVAs were carried out with verbal recall and cued recall as the dependent variables. Orthogonal contrasts comparing 1) the iconic/ deictic gesture condition and beat gesture condition vs. the no gesture condition and 2) the iconic/ deictic gesture condition vs. the beat gesture condition were conducted. Because hypotheses for feature type were simple comparisons of means, pairwise comparisons were carried out on the feature type factor, with alpha levels Bonferroni adjusted for multiple comparisons.

Effect of presenting gesture at encoding on total verbal recall. Total verbal recall is split into the recall of location, movement, and descriptive items. Because location, movement, and description items have different maximum scores, raw scores were transformed into percentages for this analysis. A 3 (Gesture Condition: no gesture, beat gesture, or iconic/ deictic gesture) x 3 (Feature Type: locations, movements, or descriptive) mixed design ANOVA was conducted, with gesture condition as the between-participants factor and feature type as a within-participant factor.

The analysis revealed a main effect of gesture condition, $F(2,169) = 3.85$, $p = .023$, partial $\eta^2 = .04$, such that children in the iconic/ deictic gesture condition verbally recalled more than children presented with beat gesture at encoding, $F(1,169) = 6.30$, $p = .013$, partial $\eta^2 = .04$ (see Fig. 2). There was no difference between the no gesture condition and the average of the two gesture conditions (beat and iconic/ deictic) in the amount verbally recalled $F(1,169) = 1.56$, $p = .213$, partial $\eta^2 = .01$. Figure 2 presents the mean percentage of location, movement and description items recalled by children during verbal recall for each gesture condition.

There was a significant main effect of feature type, $F(2,338) = 114.07$, $p < .001$, partial $\eta^2 = .40$, with more location items recalled than both movement $F(1,169) = 113.85$, $p < .001$, partial $\eta^2 = .40$, and descriptive items $F(1,169) = 175.38$, $p < .001$, partial $\eta^2 = .51$, averaged across gesture conditions. In addition, more movement items were recalled than descriptive items, across all gesture conditions $F(1,169) = 20.68$, $p < .001$, partial $\eta^2 = .11$. There was no significant interaction between gesture condition and feature type on the amount verbally recalled, $F(4,338) = 0.47$, $p = .759$, partial $\eta^2 = .01$.

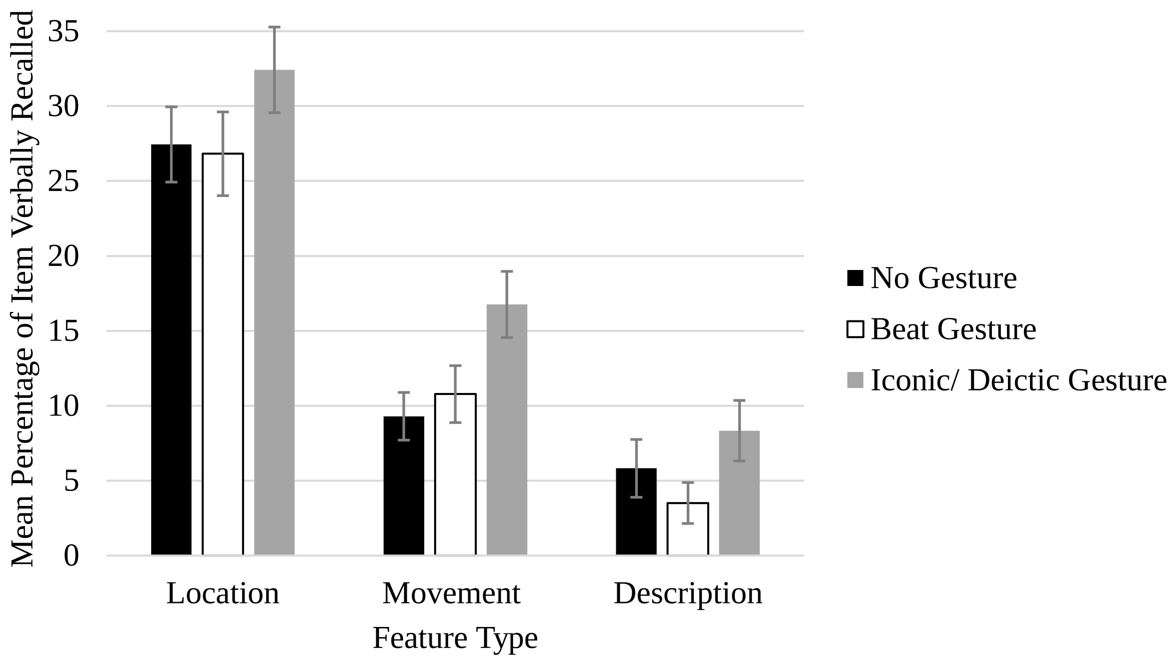

Fig. 2. Mean percentage of location, movement and descriptive items recalled during verbal recall of children for each gesture condition. Error bars represent standard errors.

Effect of presenting gesture at encoding on cued recall. A 3 (Gesture Condition) x 2 (Feature Type; excluding descriptive items as noted above) mixed design ANOVA was conducted, with gesture condition as the between-participants factors and feature type as a within-participant factor. There was a main effect of gesture condition, $F(2, 169) = 5.72$, $p = .004$, partial $\eta^2 = .07$, such that children presented with gesture (beat and iconic/ deictic) at encoding reported more at cued recall than children presented with no gesture, $F(1,169) = 10.06$, $p = .002$, partial $\eta^2 = .06$ (see Fig. 2). There was no difference in the amount recalled at cued recall by children in the iconic/ deictic, and beat gesture conditions, $F(1,169) = 1.60$, $p = .208$, partial $\eta^2 = .01$. Figure 3 presents the mean number of items recalled by children during cued recall for each gesture condition.

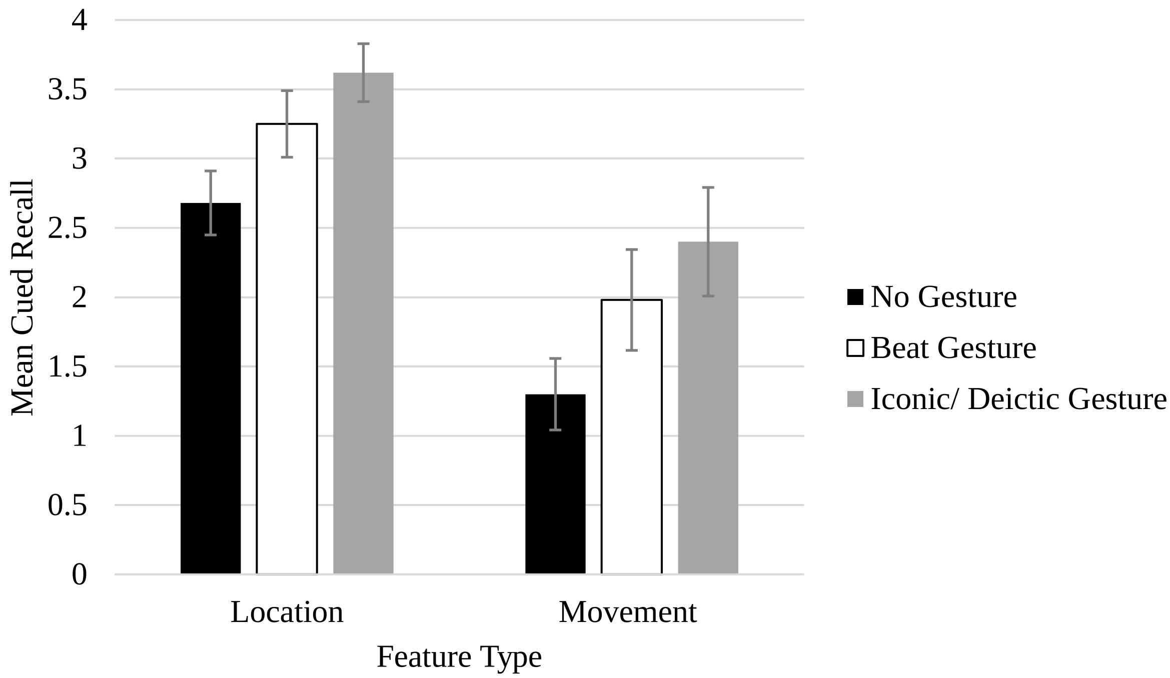

Fig. 3. Mean scores for location and movement items during cued recall of children for each gesture condition. Error bars represent standard errors.

There was a significant main effect of feature type, $F(1,169) = 34.17$, $p < .001$, partial $\eta^2 = .17$, with more locations than movements recalled across all gesture conditions. There was no significant interaction between feature type and gesture condition $F(2,169) = 0.05$, $p = .948$, partial $\eta^2 < .01$.

Discussion

Communication between individuals combines different forms of expression, both verbal and nonverbal, to establish mutual understanding between speakers and listeners. In the current study, we captured some of the complex role that gesture plays in the communication of route direction information for listeners whose language skills are still developing. Children presented with a combination of iconic and deictic gestures accompanying route directions verbally reported more information than children presented with beat gestures or no gestures accompanying the spoken route directions. This suggests that as listeners, children benefit from the presence of speakers' gestures at encoding for spatial narratives.

In spatial tasks, such as following novel route directions, listeners do not have the benefit of previous perceptual and motor experiences (Allen, 2000). Rather, the ability to successfully follow route directions requires listeners to construct a mental representation of space based on the location, movement, and descriptive information conveyed in the spoken message (Allen, 2000). Overall, children recalled more location information than movement and descriptive information, whether gesture accompanied the spoken message or not. Children also recalled more movement information than descriptive information when verbally reporting the route description. Taken together, these findings suggest that during language development listeners' recall of spatial language (i.e., location, movement and description information) is enhanced by speakers' gestures accompanying the spoken route directions.

Given that children navigate through environments as part of everyday life and that navigation involves motor components while verbal recall does not, it is important to examine the effect of gesture within the context of physical route navigation. When route direction information was accompanied by a combination of iconic and deictic gestures or beat gestures, preschoolers physically navigated more of the target route through the spatial array than children presented with only a verbal description of the target route. In contrast, beat gestures accompanying route direction information did not enhance verbal recall of the target path. This finding suggests that the simulated mental images listeners formed when presented with route directions accompanied by beat gestures may not be strong enough to enhance recall without the presence of environmental cues. Despite containing no apparent semantic meaning in and of themselves, beat gestures may act to emphasize the route characteristics which they accompany, thereby enhancing recall when prompted by environmental cues (So et al., 2012). Alternatively, iconic and deictic gestures, conveying information consistent with speech (i.e., redundant gestures), may be processed to a greater extent due to their semantic value, leading to greater recall without the presence of environmental cues (Woodall & Folger, 1981). The current findings suggest that gestures which simulate the real world (i.e., iconic and deictic) enhance recall with or without the presence of environmental cues, but that the benefit of beat gestures may only be apparent when recall is cued by the environment. Together these findings suggest that a speaker's gestures, regardless of type, play an important role in their listeners' successful physical route navigation.

To date, only one study has examined the role of observing gesture in spatial route communication for listeners (Austin & Sweller, 2014). Gestures accompanying the spoken message enhanced children's memory of a target path through a small-scale spatial array (Austin & Sweller, 2014). Together with the current study, these findings provide further evidence that gesture presents children with a valuable resource for information about spoken messages during early childhood when language skills are still developing (Sauter et al., 2012), suggesting that we may be able to facilitate knowledge acquisition and task performance during early childhood simply by using our hands when we speak.

Because gestures are abstracted actions, they are particularly good at conveying actions and as such, may be particularly beneficial for listeners when they accompany spatial messages such as route direction information. As previously mentioned, speakers' route knowledge comes from previous perceptual and motor experiences transformed into the verbal production of route directions (Allen, 2000). In contrast, listeners must create a mental model of the route based on the verbal description and accompanying gestures, then when navigating the route, listeners must compare the real-world features (perceptual experience) to their imagined mental representations (Allen, 2000). For listeners, this requires interpretation of speakers' navigation information, a continuous visual search of the environment for relevant features, matching of imagined mental representation of route features to actual route features, and estimating time and distances (Allen, 2000).

The construction of an imagined mental model of route directions places considerable demands on memory, particularly for unfamiliar environments (Allen, 2000). The iconic and deictic gestures may scaffold speech comprehension by conveying route elements through pointing, depicting gestures or through movement (Sauter et al., 2012; Tversky & Kessell, 2014). In this way, the iconic and deictic gestures accompanying spatial route information scaffolded preschoolers' spatial language comprehension. Beat gestures may also scaffold speech comprehension by emphasizing the route characteristics which they accompany (Allen, 2003; McNeill, 1992). By clarifying and emphasizing aspects of spatial messages, gestures can help to create transient maps that preserve spatial route properties such as shape and movement, thereby freeing cognitive resources for concurrent processes such as memory (Tversky & Kessell, 2014).

Gestures are rich in visuo-spatial information. Embodied cognition suggests that processing information conveyed through both speech and gesture activates the same perceptual and motor states involved in gesture production, thus facilitating the generation of an imagined mental representation of the route (Alibali & Hostetter, 2010). This activation reduces the spatial information processing demands of memory by serving as an elaborate route direction encoding strategy (Alibali & Hostetter, 2010; Just & Carpenter, 1992; Madan & Singhal, 2012). In this way, listeners may create a richer and more elaborate imagined mental representation of routes accompanied by gesture than of route directions conveyed through speech alone. Given that people have limited mental resources, richer imagined mental representation reduces the information processing demands of speech comprehension, thereby increasing the resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992).

Limitations and Future Research

Gesture can play an important role in children's learning processes (Chu & Kita, 2011; Church, Kelly, & Lynch., 2000). Gesture may facilitate learning by reducing cognitive load on speech processing, thereby freeing cognitive resources for storage and retrieval processes (Cameron & Xu, 2011; Chu & Kita, 2011). It is not yet clear, however, through which mechanism gestures accompanying spatial information aid listeners' recall. Existing research suggests that for adults, gestures that provide additional information to speech can enhance spoken information recall, but they can also detract from the listener's uptake of the information (Church et al., 2007; Goldin-Meadow & Sandhofer, 1999). Consistent with existing literature, the current study provides further evidence that for children, gestures which express the same information as speech contribute to comprehension (Goldin-Meadow, Kim, & Singer, 1999; McNeil et al., 2000). To clarify whether gestures indirectly reduce the information processing load on children's limited cognitive resources by facilitating language comprehension, future research could examine the effect of presenting gestures that provide additional information to speech on spoken message recall compared with gestures which express the same information as speech. Furthermore, future research could include measures of spatial (e.g., spatial memory) and cognitive skills (e.g., language). Documenting these differences will lead to a better understanding of how the information conveyed by a speaker's gestures influences spatial narrative comprehension during language development.

Experimental limitations regarding the use of any gesture condition in research examining spatial route direction communication are worth noting. Children and adults typically produce gestures when communicating spatial information. Although sometimes only a few gestures are produced, this is relatively rare (Austin & Sweller, in press). In the current study, the video stimuli presented to children were reviewed prior to testing, to ensure that the communication of route directions both without gestures and with accompanying beat or iconic and deictic gestures had equivalent intonation/ expressiveness. Despite precautions taken to ensure equivalence of the verbal portion of the message across conditions, however, it is possible that the communication of spatial information accompanied by either no gestures or beat gestures may have seemed unusual or odd to preschoolers, given they would usually experience such messages accompanied by iconic and deictic gestures. While gestures were produced at the same set points across the three conditions and contrived to appear natural, it is possible that there were differences in the duration of the gestures the actor produced. The difference in the duration of each gesture may have altered the amount of attention paid to the different types of gesture.

Furthermore, the Zoo stimulus used in this study was large enough for preschoolers to navigate on foot, however, may not be considered a large-scale spatial environment as it fit inside an average size room when fully constructed. Future research could examine the effect of gestures accompanying route direction information through environments larger in scale, thereby replicating these findings. Future research could also examine which listeners will benefit most from gestures accompanying spatial information by investigating if memory span and language ability moderate the beneficial effect of presenting gestures accompanying route directions. In terms of development, establishing the link between gestures accompanying speech and task performance is important for developing an understanding of gesture as a source of information for listeners.

Finally, the findings and conclusions from the current study may have been affected by a lack of power. A power analysis was performed using GPower (3.1.9.2), based on values obtained from previous research, to determine that a total sample of 228 (i.e., 76 per group) was required for 80% power to detect the effect (Faul, Erdfelder, Lang, & Buchner, 2007). Due to constraints in the recruitment process this full number was not able to be recruited.

Implications and Conclusions

Beyond the laboratory, the findings from the current study can be applied in educational and caregiving situations by teachers, parents and other early childhood carers. Encouraging individuals to produced gesture when giving spatial directions or instructions can lead to better performance of tasks and facilitate learning. Alternatively, providing teachers and caregivers with training in the production of gesture can enable speakers to effectively use gesture to scaffold preschoolers' spatial learning during language development and bring about knowledge change.

The current study found that children benefited from the presence of gesture accompanying spatial route direction information. While iconic and deictic gestures provided benefits for both verbal and cued recall, beat gestures were more limited in their effects, enhancing performance above that of no gestures for cued recall only. This study provides a greater understanding into the role gesture plays during communication for listeners, indicating that gesture is an integral part of effective spatial communication during language and cognitive development.

Chapter 4: Pointing the Way Forward: Gesture and Adults' Comprehension of Route Direction Information

Published as: Austin, E. E., Sweller, N., & Van Bergen, P. (2018). Pointing the way forward: Gesture and adults' recall of route direction information. *Journal of Experimental Psychology: Applied,* vol. 24, no. 4 pp. 490–508. https://doi.org/10.1037/xap0000168.

The present chapter presents the third empirical paper which examines the effect of gestures accompanying spatial route direction information on recall for adults. As outlined in Chapter 1, one aim of the thesis is to investigate whether gestures accompanying route direction information can enhance the recall and successful task performance for adult listeners. This paper achieves this by presenting adults with verbal route directions through a building on the university campus and, depending on assigned condition (no gesture, beat gesture, or iconic / deictic gestures), accompanying gestures. This builds on the previous chapter which illustrated that a combination of iconic and deictic gestures and, to a lesser extent, beat gestures play an important role in listeners' encoding and recall of spatial information. Further, the results of Chapter 2 demonstrate age related differences in the production of gestures accompanying route direction information, suggesting the function of gesture changes throughout development. Type of speech and gestures were manipulated in the study presented in Chapter 3, based on the respective rates of production found in Chapter 2, but it is questionable whether similar results would be obtained at older ages, such as early adulthood. Given the results of Chapters 2 and 3, it is reasonable to expect that there might also be differences in recall for listeners depending on the types of gestures accompanying route direction information. Furthermore, if the function of gesture is to reduce cognitive load, then we would expect the beneficial effect of gesture on listeners' recall to be moderated by listeners' cognitive ability.

People use cognitive abilities (e.g., spatial ability, language, and memory) to encode, retain, recall and communicate spatial information (Allen, 2000; Chu & Kita, 2008; Nothegger, Winter, & Raubal, 2004; Vanetti & Allen 1988). Differences in cognitive ability, such as spatial ability, can predict effectiveness of route direction communication and physical navigation performance. For instance, adults higher in spatial ability perform better than individuals with lower spatial ability when route information is presented as written instructions (Vanetti & Allen, 1988), virtual navigation (Wen, Ishikawa, & Sato, 2011), and through navigation aids such as written, map, or turn-by-turn audio guidance (Wochinger & Boehm-Davis, 1995). Despite the importance of spatial ability in spatial communication for speakers, there has been no investigation to date into whether gestures have a differential impact on the recall of route direction information for listeners with varying levels of spatial abilities. It is possible that individuals with lower spatial abilities need the visual and motor information conveyed in gesture to a greater extent than individuals higher in spatial ability.

The present chapter presents an empirical investigation into the effect of gestures on adult listeners' encoding and subsequent recall of route direction information. Both studies in this chapter also examine whether different types of cognitive abilities moderate the beneficial effect of gestures accompanying spatial information for listeners. In summary, this chapter addresses Aim 3 of the thesis, by exploring the effect of a speaker's gestures accompanying route direction information on recall for adults, as well as further clarifying the role of cognitive abilities in moderating the effect of gesture.

Student Statement of Contributions

I was the major contributor to this co-authored paper. I was responsible for developing the conceptual argument and study design, and did this in consultation with my primary supervisor, Naomi Sweller and my associate supervisor Penny Van Bergen. I also collected all data and conducted the statistical analyses with input and advice from Naomi Sweller. I drafted the first version of the manuscript, and both Naomi Sweller and Penny Van Bergen provided feedback and suggestions on multiple versions of the manuscript.

As outlined in Chapter 1, this paper has been submitted to the *Journal of Experimental Psychology: Applied.* The full reference is:

Austin, E. E., Sweller, N., & Van Bergen, P. (2017). *Pointing the way forward: Gesture and adults' comprehension of route direction information.* Manuscript submitted for publication.

Pointing the Way Forward: Gesture and Adults' Recall of Route Direction Information

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Submission date: 15th June 2017

Abstract

Spatial communication tasks, such as following route directions through unfamiliar environments, place considerable demands on multiple cognitive processes, including language comprehension and memory. Gestures accompanying spoken route directions may aid task performance by enhancing cognitive processes such as language and memory processing. It is not yet clear whether different kinds of gesture might influence the processing of route information in different ways. In two experiments, we examined how different gestures would enhance or reduce listeners' recall of spatial information when given route directions through an unfamiliar building. Adults were randomly allocated to one of three gesture conditions: no gesture (speech only), beat gesture (speech accompanied by simple rhythmic gestures), or iconic-deictic gesture (speech accompanied by iconic and deictic gestures). Recall was measured verbally, by recalling the route aloud, then physically, by walking the route. In Experiment 1, redundant gestures that mirrored verbal route directions did not enhance listeners' verbal recall or route navigation. In Experiment 2, when the verbal route directions were edited to be incomplete, non-redundant gestures enhanced recall to the level seen when hearing all information through speech. These findings suggest that gestures enhance recall when compensating for missing verbal information, but not when they replicate verbal information.

Keywords: gesture, encoding, spatial listener, recall

Pointing the Way Forward: Gesture and Adults' Recall of Route Direction Information

Effective communication involves the integration of multiple forms of expression, such as words, tone, and hand gestures, to establish understanding between individuals (Tversky, 2011). Spoken language enables individuals to easily and efficiently share complex abstract and concrete information with one another (Tversky, 2011). Similarly, gestures express and influence thoughts: both abstract and concrete (Cassell, Kopp, Tepper, Ferriman, & Striegnitz, 2007; Tversky & Kessell, 2014). Through different hand shapes, manners, and positions, for example, the gestures accompanying speech may convey elements of dialogue through pointing, enacting gestures, or movement (Tversky, 2011; Tversky & Kessell, 2014). In the case of spatial information, such as route navigation, gestures also allow actions to be represented visually in a way not possible with verbal communication alone.

Navigating new environments is an everyday part of life (Blades & Medlicott, 1992; Ehrlich, Levine, & Goldin-Meadow, 2006; Taylor & Tversky, 1996). Not surprisingly, therefore, people frequently ask others for route directions to assist in finding the way (Blades & Medlicott, 1992; Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999). Effective route directions typically combine locations (e.g., the church), movements (e.g., turn left), and descriptions (e.g., it's really old) in a coherent spatial narrative (Cassell et al., 2007; Daniel & Denis, 2004), and may also specify salient points along the route – decision points – which require the traveler to make a decision about what direction to take (e.g., turn left or continue straight; Allen, 2000). Because gestures allow for the visual representation of movement and scale, they are particularly good at conveying abstract versions of these actions (Novack & Goldin-Meadow, 2015; Tversky, 2011). They may therefore be particularly beneficial for listeners when they accompany spatial messages such as route directions. To date, however, there has been limited investigation of the effects of gesture accompanying spatial information on listener recall.

Types of Gesture

Spontaneous gestures, produced in the presence of speech, are typically classified in two distinct ways: according to meaning or according to imagistic quality (Alibali, 2005; Cassell et al., 2007; Cassell, McNeill, & McCullough, 1999; Kendon, 1972, 2004; McNeill, 1992). When classified according to meaning, spontaneous gestures fall into two broad categories: meaningful (iconic, metaphoric, and deictic) gestures and non-meaningful (beat) gestures (Kendon, 1972, 2004; McNeill, 1992). Spontaneous gestures can also be divided into two categories according to imagistic qualities: imagistic (iconic and metaphoric) gestures, which support meaning-making from the speech itself, and non-imagistic (deictic and beat) gestures, which highlight aspects of the speech (Alibali, 2005; Cassell et al., 2007; Cassell, McNeill, & McCullough, 1999; McNeill, 1992). Iconic gestures convey meaning by pantomiming a concrete image of objects or actions referred to in speech (Allen, 2003; McNeill, 1992). For example, a speaker may pantomime the actions of climbing while accompanying the statement “we went up the ladder”: thus conveying to the listener how the ladder was climbed. Metaphoric gestures also convey meaning via image, but of abstract concepts (Allen, 2003; McNeill, 1992). For example, a speaker may portray two objects circling whilst explaining chemical reactions: thus conveying to the listener information about how chemical compounds interact. In both cases, it is not just the action but the relationship of the action to the accompanying speech that determines if the gesture is classified as iconic or metaphoric (Kendon, 1972, 2004; McNeill, 1992).

In contrast, non-imagistic gestures do not convey an image, but highlight aspects of speech or the rhythmic structure of speech (Kendon, 2004). Deictic gestures convey meaningful information about location, movement, or direction through pointing (Allen, 2003; McNeill, 1992). For example, pointing to the left accompanying the statement "the tree is over there", conveys to the listener the location of the tree. Conversely, beat gestures convey no apparent meaning (Allen, 2003; McNeill, 1992). These simple rhythmic hand movements which match the rhythm of speech are, therefore, different to the three former gesture types (Allen, 2003; McNeill, 1992). Performed wherever the hands happen to be, beat gestures are typically biphasic, small, low energy, rapid flicks of the fingers or hands (McNeill, 1992).

The Function of a Speaker's Gestures for Listeners

For speakers, the influential relationship between the body (producing gestures) and the mind (thought processes) is bidirectional, with gesture production influencing how one thinks and reasons about a problem, and thought processes influencing gesture production in turn (Wilson, 2002). For listeners, however, the influence of speaker gestures on a listener's processing is less well understood. Although it is well established that recall for non-spatial spoken information may be enhanced by simultaneously viewing gestures, it is not yet clear why this is the case.

According to Dual Coding Theory and Multimedia Learning Theory, listeners construct separate mental representations from information conveyed through speech and gesture (Mayer, 2009; Paivio, 1990). In other words, listeners construct a mental representation of the speech content as well as a mental representation of the gesture content. The two mental representations are then integrated via referential connections (Mayer, 1997, 2009; Piavio, 1990). The referential connections between mental representations allow the verbal and nonverbal systems to trigger activity in each other. In this way, seeing a gesture activates the corresponding representation of speech content through spreading activation (Paivio, 1990). The processing of information conveyed through speech and gesture (i.e., dual coding) benefits listeners' cognitive processes because if one mental representation is forgotten, then the other may still be accessible in memory (Paivio, 1990).

The Role of Gesture for Listeners During Communication

As previously mentioned, gestures accompanying spoken information facilitates adult listeners' recall of non-spatial content (e.g., Beattie & Shovelton, 1999; Church, Garber & Rogalski, 2007; Cocks, Morgan, & Kita, 2011; Feyereisen, 2006). Church et al. (2007) presented adults with a video of an actor producing statements, some accompanied by gestures, some not accompanied by gestures. Adults recalled items accompanied by gestures to a greater extent than items unaccompanied by gestures, suggesting that the referential connections between verbal and visual mental representations facilitated the recall of information.

Feyereisen (2006) examined the role of gesture meaning in remembering spoken information. Gestures that conveyed no apparent semantic information did not enhance listeners' recall. Meaningful gestures increased sentence recall and recognition, while meaningful gestures that were mismatched to speech content did not facilitate listeners' recall. Taken together, these findings suggest that listeners create a mental representation of both spoken and gesture content. In addition, consistency (i.e., some level of redundancy) in the messages conveyed through speech and gesture is important for listeners' integration of mental representations, cognitive processes and subsequent recall (Feyereisen, 2006; Mayer, 1997, 2009; Piavio, 1990). For listeners, the potential beneficial effect of gesture at encoding on the processing of task information may be particularly important for spatial tasks such as encoding and recalling route information.

Spatial tasks, unlike non-spatial tasks, tap into an individual's capacity to visualize space, to understand spatial relations, and to orient themselves in small-scale (i.e., figural space) and large-scale (i.e., life size) environments (Chu & Kita, 2011). When conveying route direction information through large-scale space, speakers convey salient route elements in speech as well as through pointing and enacting gestures (i.e., deictic and iconic gestures; Austin & Sweller, in press; Cassell et al., 2007; Mark et al., 1999; Tversky & Kessell, 2014). The morphologic features of these gestures often correspond to the visual aspects of spoken referents (Cassell et al., 2007). For example, a flat hand shape with the palm vertically orientated typically refers to objects with an upright plane, such as a building referred to in speech (Cassell et al., 2007). Listeners, however, must construct a mental representation of the route (i.e., visualize space, understand spatial relations and orientation) without the benefit of previous perceptual and motor experience of the environment (Allen, 2000; Blades & Medlicott, 1992; Mark et al., 1999; Wochinger & Boehm-Davis, 1995). Spatial mental representations require listeners to select and organize salient information about the environment and map that information onto an internal representation (Tversky & Kessell, 2014).

Gestures, like pictures, may allow salient environmental information to be extracted from the spoken message, thereby reducing cognitive processing demands (Eitel, Scheiter, Schüler, Nyström, & Holmqvist, 2013; Schüler, Arndt, & Scheiter, 2015). Eitel et al., (2013) presented adults with a verbal description of the system structure and functions of a pulley, either preceding or accompanied by a schematic picture of the pulley system, or no picture. Adults presented with the pulley system picture prior to the verbal description had better comprehension of the pulley systems function than adults presented with a verbal description only.

Furthermore, in examining how individuals process information from text and pictures, Schüler et al. (2015) reported that individuals integrate specific information conveyed through pictures with general information conveyed through text into a single mental representation. Taken together, the spatial information extracted from pictures scaffold the construction of a mental model. It is possible that gestures, as abstracted versions of action, facilitate salient environmental information extraction and the construction of a spatial mental representation.

Route direction learning is enhanced by temporal-spatial ordering of route information with large amounts of information to recall, not all of which however is important for physical route navigation (Allen, 2000). The construction and integration of verbal, visual and motor mental representations of the route places considerable demands on working memory, particularly when the listener is unfamiliar with the environment being described (Allen, 2000). If task load is unmanageable due to length of instructions or due to the unusual nature of the environment, then some information may never be encoded (Allen, 2000). It is possible that an overlap in spatial information conveyed through speech and gesture may aid listeners' mental representation and the referential connection between them. To better understand the role of gesture in mental model creation, it is important to examine the effect of gesture accompanying spatial information on listeners' capacity to accurately recall route details, as well as the extent that participants' inferences are consistent with, but do not directly match, the route directions (i.e., gist).

For listeners, gestures accompanying route directions may play a unique role in influencing the recall of spatial information. Encoding spatial route direction information, unlike non-spatial information, requires the processing of verbal, visual and motor / action information (Hostetter & Skirving, 2011). It is possible that the additional processing of visual and motor information provided by gestures reduces the information processing demands of verbal information, by serving as an elaborate encoding strategy (Just & Carpenter, 1992). In this way, listeners may create a richer and more elaborate mental representation of spoken messages that are accompanied by gesture than of messages conveyed through speech alone. Given that people have limited mental resources, the processing of visual and motor information simultaneously may also reduce the information processing demands of language comprehension, thereby increasing cognitive resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992). If gestures offer a way for listeners to encode and process information, then it is important to examine the effect of visual and motor information conveyed through gesture on the recall of spatial information.

To date, there has been limited investigation into the effect of a speaker's gestures on listeners' successful route recall (Austin & Sweller, 2014; Van Wermeskerken, Fijan, Eielts, & Pouw, 2016). Using a small-scale desktop spatial array made of Lego, Austin and Sweller (2014) presented preschool-aged children (4 to 5 years) and adults with route directions accompanied by either no gestures, beat gestures, or both imagistic and non-imagistic gestures (a combination of iconic, deictic, metaphoric and beat gestures). Children presented with either beat gestures or a combination of gestures recalled more route information than did children presented with route directions accompanied by no gestures. For adults, however, gestures did not enhance recall of the route. Van Wermerkeren et al., (2016) also demonstrated that children presented with tracing gestures or a combination of tracing and depicting gestures reported more of a route compared with children presented with depicting gestures or no gestures accompanying route information. It is possible that gestures accompanying route directions benefited children, but not adults, due to differences in cognitive processing capacity. With their larger vocabulary and cognitive capacity, adults may not have needed accompanying gestures to facilitate the creation of a spatial mental representation of the route, thereby alleviating cognitive demands for the small-scale spatial task.

Despite the potential importance of gesture for the recall of route information, at least in children, the effects of gesture accompanying spatial content may depend on the scale of space used in the task. Spatial tasks differ by the scale, with implications for cognitive processing (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Austin and Sweller (2014) used a small-scale desktop Lego array that could be viewed from a single viewpoint. Large-scale environments cannot be viewed from a single viewpoint, however, and may therefore draw on different processing abilities. When navigating through buildings and towns, for example, where the locations described are larger than the individual, the listener must construct a mental representation of the environment without visual cues to base it on. Without previous perceptual and motor experiences of the environment, creating an imagined mental representation of the environment places greater demands on listeners' cognitive resources (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). One factor that may influence the role of gesture in scaffolding spatial mental representations during spatial task performance are task relevant abilities, such as spatial ability.

Individual Differences – Spatial Ability

Successful route navigation requires listeners to match their mental representation of the route to the perceptual experience, estimating factors such as time and distance as they go (Vanetti & Allen, 1988; Wochinger & Boehm-Davis, 1995). It is therefore not surprising that spatial abilities such as visualization, mental construction of spatial relations, and orientation, which are necessary to anticipate and track environmental changes and remain orientated within the environment (Chu & Kita, 2011; Hostetter & Alibali, 2007; Vanetti & Allen, 1988), can predict the effectiveness of route direction communication and physical navigation performance. Adults with higher spatial ability perform better than adults with lower spatial ability when route information is presented as written instructions (Vanetti & Allen, 1988), videos (Wen, Ishikawa, & Sato, 2011), and through navigation aids (e.g., a map with a route plotted; turn-by-turn audio/ satellite navigation; Wochinger & Boehm-Davis, 1995).

Despite the importance of spatial ability in spatial communication, there has been no investigation to date into whether gestures have a differential impact on the recall of route direction information for listeners with varying levels of spatial abilities. Given individuals higher in spatial ability perform better on spatial tasks involving written and oral route directions, however, it is possible that individuals with lower spatial abilities need the visual and motor information conveyed in gesture to a greater extent than individuals higher in spatial ability. That is, individuals with lower spatial abilities must use more cognitive resources creating visual mental representations than individuals with higher spatial abilities. As a result, individuals with lower spatial abilities would have fewer cognitive resources available for the referential connections, making recall less likely. It is also possible that the difference in low and high spatial ability capacity is not in the creation of the visual mental representation, but in the creation of the referential connection. Gestures may alleviate the cognitive demands of the task by facilitating spatial information processing (i.e., the construction of visual mental representations and the connections between mental representations). If individuals higher in spatial ability effectively process spatial content without the aid of gestures, then gestures accompanying spatial content may be particularly beneficial for individuals lower in spatial ability.

Present study

Our primary goal in the current study was to examine the effect of gesture at encoding on listeners' recall of spoken spatial information. While gesture is frequently used by speakers when conveying spatial information, including route instructions, we do not yet know its impact on listener recall. As noted above, gesture is important in adults' communication of spatial information. However, only research by Austin and Sweller (2014) investigating the effect of gesture on adult listeners' recall has used spatial information stimuli. This study examined the role of gesture at encoding for listeners' recall of small-scale spatial information, but not the kind of large-scale information used in real-life route navigation. Furthermore, Austin and Sweller did not distinguish between different types of gesture, comparing all types of gesture to beat gesture and no gesture. Drawing on findings about gesture in other domains, however, the meaningfulness of the gesture is likely to be important in determining recall. Finally, spatial abilities may be important for the processing of spatial information conveyed through speech and gesture. Whereas previous research on gesture has considered recall for non-spatial words and sentences, spatial tasks instead require inspecting, imagining, or mentally transforming objects and environments. Thus, the re-representation of action through gesture may be particularly beneficial for spatial task performance at different levels of spatial ability.

To determine the role of gesture during spatial communication for listeners, the question we addressed in this paper is whether the gestures that speakers produce when conveying large-scale route directions have an impact on whether listeners subsequently recall that information. Furthermore, examining the effect of gesture accompanying spoken messages for individuals with different spatial abilities will enhance our understanding of the information processes involved in comprehending spatial messages and procedural knowledge acquisition. Two experiments examined the relation between the presence of different types of gestures at encoding of route information and listeners' subsequent recall, as well as the effect an individual's cognitive abilities have on this relationship.

Experiment 1

The aim of Experiment 1 was to examine whether gestures accompanying route directions through a large-scale environment benefit listener recall. Given that the processing of complex spatial information such as route directions places considerable demands on cognition, we hypothesized that accompanying spatial instructions with gesture would enhance listeners' encoding and subsequent recall of these directions (i.e., location, movement, and description information). In particular, the combination of meaningful gestures (iconic and deictic) which typically accompany large scale route directions, should enhance recall compared with non-meaningful gestures (beats) which, while still produced with spoken spatial information, convey no apparent semantic meaning (Allen, 2003; Austin & Sweller, in press). This may be true not only for verbal free recall, which is important for verbal clarification of comprehension, but also for physical route navigation. Indeed, given that the purpose of route communication is to enable listeners to successfully travel from A to B, successful physical route navigation is arguably the most important indicator of recall for the role of gesture in spatial communication for listeners.

To investigate the effect of gestures accompanying large-scale route information on listener recall, we presented undergraduate adult participants with a video of an actor describing a route into and around a building. Depending on the condition that participants were allocated to, the actor accompanied his descriptions with either gesture or no gestures. Gestures were further subdivided into either meaningful (a combination of iconic and deictic) or non-meaningful. Participants were then asked to recall the route: first verbally, and then by physically walking the route. It was firstly expected that the presence of gesture at encoding would lead to better recall, both verbal and physical route navigation recall, than would the same message conveyed with no accompanying gesture. Secondly, it was expected that individuals presented with a combination of iconic and deictic gestures accompanying route directions would recall more verbally and when navigating the route, than individuals presented with beat gestures accompanying the verbal message. Finally, if spatial ability influences the cognitive resources used in the comprehension of a spoken spatial message, then an individual's spatial ability should influence the relationship between the beneficial effect of gesture accompanying a spoken message and subsequent verbal and physical route navigation recall. Thus, we expected that higher spatial ability would predict greater recall and that gestures accompanying spatial content would be particularly beneficial for individuals lower in spatial ability.

Method

Participants

Participants included 86 adults recruited from an introductory psychology unit at Macquarie University. There were 39 males and 47 females, and participants ranged in age from 18 to 39 years (*M* = 19.84, *SD* = 3.17). This study was approved by the Macquarie University Faculty of Human Sciences, Human Research Ethics Committee (HREC). Participants were given an information sheet and consent form indicating the purpose and procedure of the study. Participants were given course credit for participating.

Design

There was one independent variable (gesture type) with three levels (iconic-deictic gesture, beat gesture, and no gesture) and two dependent variables (verbal recall and physical route navigation). First, participants were randomly allocated to one of three conditions: iconic-deictic gesture (n = 29), beat gesture (n = 29), or no gesture (n = 28). Next, all participants were presented with a video in which an adult male provided a verbal description of a target path in and around an unfamiliar building on campus and, depending on assigned condition, accompanying gestures. Last, all participants were asked to complete a measure of self-reported spatial ability and building familiarity.

Materials

Instructional video. Three videos were created of an actor conveying the target path which included a total of 4 left turns and 5 right turns. The target path script comprised a total of 41 statements, with the frequency and type of statement matched to the average frequencies and type of phrases produced by adults and preschool aged children when conveying route directions (see Austin & Sweller, in press). In total, there were 7 statements containing location only information (i.e., a statement mentioning a location with no reference to any movement to be taken), 2 containing descriptive location information (i.e., a statement including both the location and a description of its characteristic features with no reference to movement), 8 containing movement only information (i.e., a statement prescribing movement with no reference to a location), 2 containing descriptive movement information (i.e., a statement prescribing movement and a description of its characteristic feature with no reference to a location), 17 containing location and movement information (i.e., a statement prescribing movement with reference to a location), and 5 containing descriptive location and movement information (i.e., a statement prescribing movement with reference to a location which includes a description of a characteristic feature of one or both).

Participants in the iconic-deictic gesture condition were presented with a video containing the verbal description of the target path and 41 accompanying gestures: deictic (n=33) and iconic (n=8), based on the frequency and type of gestures most commonly produced by adults and preschool aged children when conveying route directions (Austin & Sweller, in press). For example, “The couches are on the left” (deictic gesture: narrator points to the left as the words “on the left” are verbalized), “There is a large flat grass area in front of you” (iconic gesture: narrator sweeps hand from left to right with palm facing down as the words “large flat” are verbalized; See Figure 1). The video presented to participants in the beat gesture condition consisted of the verbal description and a total of 41 accompanying beat gestures (i.e., simple rhythmic hand movements that contained no apparent semantic information; See Figure 2). Prescribed gestures for the iconic-deictic and beat gesture conditions were performed at the same set points within the verbal script for each video (see Appendix A for full script and gesture set points). Participants in the no gesture condition were presented with a video containing only the verbal description of the target path while the narrator’s hands remained still. To eliminate any biasing effects of lexical stress (Field, 2009), the confederate practiced the script several times prior to recording, making sure to stress the movements and locations in an identical manner for all videos.

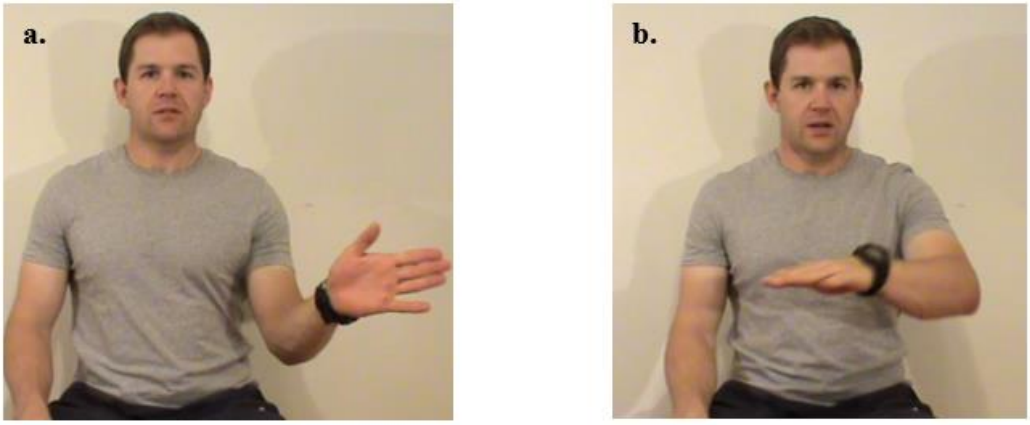

Fig.1. Screenshots from the iconic-deictic gesture condition video depicting actor gestures accompanying a. “The couches are on the left”, and b. “There is a large flat grass area in front of you”

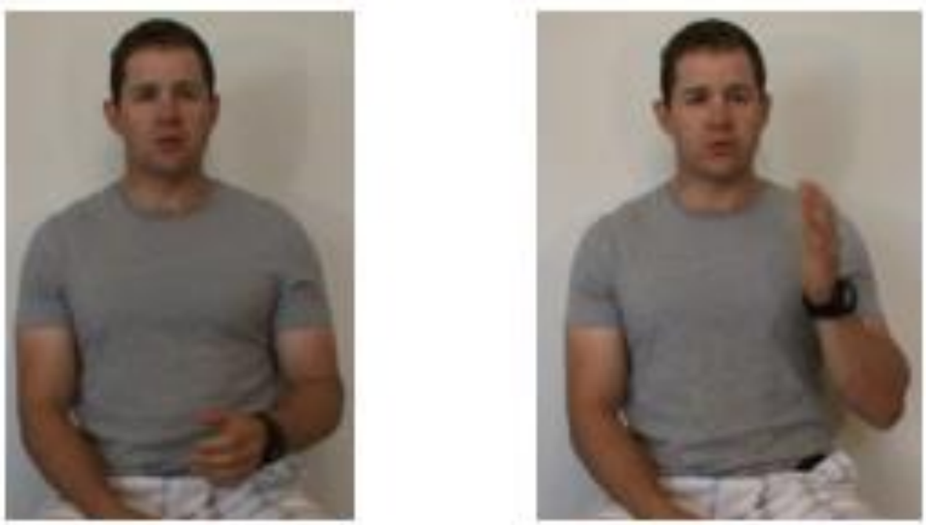

Fig. 2. Screenshots from the beat gesture condition video depicting the bottom and top phase respectively, of the beat gesture.

Spatial ability measure. Participants completed the Santa Barbara Sense of Direction Scale (SBSOD), which consists of 15 statements about spatial and navigational abilities, preferences, and experiences on a scale of 1 (strongly agree) to 7 (strongly disagree; Hegarty Richardson, Montello, Lovelace, & Subbiah, 2002). A rating of 4 indicated that the participant neither agreed nor disagreed with the statement. Approximately half the items were stated positively (e.g., "I am very good at reading maps") and half negatively (e.g., "I have trouble understanding directions"). Positively stated items were reverse scored so that a higher SBSOD score indicated a better sense of direction. This scale has a reported internal reliability of .88 and a Cronbach's alpha of .82 for the current study.

Building familiarity measure. Participants completed a building familiarity questionnaire measuring their familiarity with the building prior to their participation which consisted of the following statements: "I am familiar with the practice route", "I am familiar with the test route", and "I am familiar with this building", on a scale of 1 (strongly agree) to 7 (strongly disagree). A rating of 4 indicated that the participant neither agreed nor disagreed with the statement. A higher building familiarity score indicated less familiarity with the building.

Procedure

Once informed consent was obtained, participants were told they would be watching a video of a description of a route. The video was presented on a screen measuring 51cm width x 29cm height (20.1 x 11.4 inches). The actor appeared in the center of the screen facing forward. Participants sat approximately 50cm (19.7 inches) from the screen. The experimenter instructed participants "You should watch and listen to the description carefully and remember as much of it as possible because I will ask you to tell me the directions as if I have never heard them before, including as much detail as possible". Participants were then presented with the video of the route description. After a join-the-dot filler task lasting 120 seconds, participants were asked, "Can you now tell me the route exactly as it was described in the video?". Participants' spontaneous gestures and other physical actions made when verbally recalling the route were also of interest because they indicate non-verbal recall, therefore no specific instructions regarding gesture were given. To ensure each participant had recalled everything they could, they were asked “Is there anything else you would like to add” when they had finished giving their verbal description. No directional feedback or confirmation was provided by the experimenter. During verbal recall, participants’ verbal responses were videotaped and transcribed for analysis.

Participants were then told “Now you are going to walk the route you heard in the route description, following the exact route without changing it in any way. If you have any doubts then you should guess the correct pathway on the basis of what you do remember from the description”. During physical path navigation (i.e., physical route navigation recall), the experimenter walked behind the participant recording the path taken on a paper map of the building. If a participant stated that they were unsure where to go next, or if they asked the experimenter for help, they were asked: “where would you go if forced to continue?”. If participants physically deviated from the route or halted and could go no further, the experimenter marked the location on the map. After returning to the room, participants completed the SBSOD and the building familiarity measure. The entire procedure took 25 to 30 minutes per participant, depending on the length of each participant’s verbal response and walking speed. All participants completed the task in one session.

Coding

Verbal recall. Participants’ own speech and gestures produced during verbal recall were transcribed and coded following the procedure used by Austin and Sweller (2014). Speech was transcribed verbatim, including filled pauses (e.g., umm) and hesitations, and coded for specific route information (location, movement, and descriptions) and for gist (the extent that participants' inferences were consistent with but did not directly match the route directions). Spontaneous gestures used to accompany verbal recall were also recorded (transcribed according to hand shape and movement), and were coded both according to type (iconic, deictic, metaphoric, beat) and to the verbal information that they accompanied (i.e., location, movement, or descriptive information).

To determine if the presence of gesture enhances the accuracy of listeners' recall, the verbal component of each transcript was coded for accurate recall of location, movement, and description information. For example, when explaining the target path, the video narrator had instructed participants to "Walk in through the double glass doors". If during verbal recall the participant said, "go in through the doors" the location and movement were coded as being correctly recalled. The description was not coded as being correctly recalled, however, because the participant did not state that the doors were "double glass". The maximum score for location, movement, and description recall was 32, 32, and 9, respectively, with a total recall score out of 73. Secondly, to determine if the presence of gesture enhances listeners' recall for the basic ideas within the route directions without emphasis on the specifics of the directions, the verbal component of each transcript was coded for gist. The gist of a statement was counted as correct if the participant mentioned an aspect of that statement or described the statement in words other than those used in the target description. For example, if the participant said, "via the front doors", then the gist of the target statement was counted as correct. The maximum score for gist recall was 41.

Participants' spontaneous use of gesture was coded in three ways. First, the gestures were coded as serving a functional purpose (e.g., scratching), being a direct manipulation of an object (e.g., picking up a pen), or displaying an emblem (e.g., thumb and pointer finger joined together to mean “okay”). Second, the gesture were categorized into one of four categories (i.e., deictic, iconic, beat, or metaphoric) according to descriptions outlined by McNeill (1992). Third, the gestures were coded for the location, movement, or descriptive information they conveyed and included in participants’ verbal recall score. A location, movement, or description item was coded as correct if the participant demonstrated the term through gesture. For example, if the participant said, “go in through the glass doors” accompanied by a gesture pantomiming two doors opening/ closing, then the location and description were counted as correct.

Physical route navigation. To capture the effect of gesture on the accuracy of participants’ route navigation, their physical route recall was recorded on a map and coded according to the extent their navigation directly matched the route directions. Participants’ physical route navigation recall was coded in two ways: a decision point score, and a critical deviation point score. Decision point scores reflected the number of decision points along the target path reached by participants when physically navigating the route. The target path moved through 20 decision points along the route. A decision point score of 20 reflected that the participant reached all decision points along the target path. Participants who deviated from the route and then returned to the route continued to get decision points. For example, the route exits the building and turns left, then left again, then enters the building on the opposite side. If participants turned right and then right again, entering the building through the correct door, then their route was coded according to the decision points they navigated through. In this example, the participant received decision points until they deviated from the route and they received decision points once they rejoined the route (excluding the decision points they did not go through). Critical deviation point score reflected the last decision point reached, from which the participant made a critical deviation from the target path when physically navigating the route. A critical deviation score of 20 reflected no deviation from the target path.

Reliability

To determine inter-rater reliability, two coders independently coded 25% of the transcript and video data. Only the first coder was aware of the purpose of the task. Inter-rater reliability was evaluated through single-rater intraclass correlations (ICCs), with a consistency model. For speech coding during verbal recall, intraclass correlations were obtained for total locations ($ICC = .998$, $p < .001$), total movements ($ICC = .997$, $p < .001$), total descriptions ($ICC = .987$, $p < .001$), total recall ($ICC = .939$, $p < .001$), and total gist ($ICC = .993$, $p < .001$). For gesture coding during verbal recall, intraclass correlations were obtained for deictic gesture ($ICC = 1.000$, $p < .001$), iconic gesture ($ICC = 1.000$, $p < .001$), beat gesture ($ICC = 1.000$, $p = .001$), and metaphoric gesture ($ICC = 1.000$, $p < .001$). For physical navigation recall coding, intraclass correlations were obtained for decision point score ($ICC = .998$, $p < .001$), and critical deviation point score ($ICC = .972$, $p < .001$). Across all categories scores were above .900, and the first coder, therefore, coded the remainder of the transcripts and videos.

Results and Discussion

Participants' verbal and non-verbal recall of route direction information was first analyzed for the accuracy of specific kinds of route information, then for route gist, and finally for the effect of gesture on participants' physical route navigation. Given that the study was conducted on campus, it is possible that the building and surrounding environment may be familiar to participants. A one-way analysis of variance (ANOVA) with gesture condition as the between subjects factor was carried out for building familiarity. The analysis revealed no significant difference between the no gesture condition (*M* = 4.71, *SD* = 1.36), beat gesture condition (*M* = 4.90, *SD* = 1.40), and iconic-deictic gesture condition (*M* = 4.55, *SD* = 1.32) in participants' building familiarity ($F(2,83) = 0.47$, $p = .629$, partial $\eta^2 = .01$).

Accuracy of verbal recall. To examine the effect of different kinds of gestures accompanying route directions on the amount and type of information verbally recalled, we compared recall for location, movement, and descriptive information. Because each category has a different maximum score, raw scores were transformed into percentages for this analysis. A 3 (Gesture Condition: no gesture, beat gesture, or iconic-deictic gesture) x 3 (Feature Type: locations, movements, or descriptive) mixed design ANOVA was conducted, with gesture condition as a between-participants factor and feature type as a within-participant factor. Participant SBSOD was centered at the mean and entered as a predictor. For analyses where the assumption of sphericity was violated, Greenhouse-Geisser adjusted ε results are reported. Significant effects were followed up with pairwise comparisons (simple effects analyses) with a Bonferroni adjustment to *alpha* values ($p < .017$) with unadjusted *p* values reported.

The analysis revealed no main effect of gesture condition, $F(2,80) = 0.33$, $p = .718$, partial $\eta^2 = .01$ (see Table 1). There was a main effect of feature type, $F(1.37,109.56) = 4.33$, $p = .028$, partial $\eta^2 = .05$, such that more location items were recalled than movement items ($F(1,80) = 11.14$, $p = .004$, partial $\eta^2 = .07$), but not more than descriptive items ($F(1,80) = 6.58$, $p =.036$, partial $\eta^2 = .04$). There was no difference in the number of movement and descriptive items recalled ($F(1,80) = 0.69$, $p = 1.00$, partial $\eta^2 < .01$). There was a main effect of SBSOD, $F(1,80) = 5.34$, $p = .023$, partial $\eta^2 = .06$, such that as SBSOD scores increased, recall also increased. There was no significant interaction between gesture condition and feature type on the amount of detail verbally recalled, $F(2.74, 109.56) = 1.01$, $p = .388$, partial $\eta^2 =.03$, or between SBSOD score and gesture condition, *F*(2,80) = 1.10, *p* = .337, partial η^2 = .03. There was however a significant interaction between SBSOD score and feature type, *F*(1.37, 109.56) = 6.62, *p* = .006, partial η^2 = .08, such that the effect of SBSOD score was greater for the recall of location and movement information than for descriptive information. There was no significant three-way interaction between feature type, gesture condition and SBSOD, *F*(2.74, 109.56) = 1.82, *p* = .152, partial η^2 =.04.

Table 1

Estimated marginal mean (and Standard Error) Location, Movement, Description, Gist, Decision Point and Critical Deviation Point recall by Gesture Condition

	Gesture Condition		
	No Gesture	Beat Gesture	Iconic-deictic Gesture
Locations	35.85 (2.49)	37.62 (2.39)	38.37 (2.39)
Movements	34.61 (2.25)	34.55 (2.16)	34.45 (2.16)
Descriptions	31.18 (2.91)	36.50 (2.80)	31.66 (2.80)
Gist	18.47 (1.13)	19.08 (1.08)	19.15 (1.08)
Decision Points	14.86 (0.92)	14.94 (0.88)	14.69 (0.88)
Critical Deviation Point	7.02 (0.87)	9.77 (0.83)	8.35 (0.83)

Note. Standard Errors appear in parentheses

Gist of verbal recall. Participants' gist recall score was entered into an ANOVA with gesture condition as a between-subjects factor and participant SBSOD (centered at the mean) entered as a predictor. The analysis revealed no main effect of gesture condition, *F*(2,80) = 0.11, *p* = .894, partial η^2 < .01 (see Table 1). There was a main effect of SBSOD *F*(1,80) = 9.53, *p* = .003, partial η^2 =.11, such that as SBSOD increased participant gist recall also increased. There was no significant interaction between SBSOD score and gesture condition, *F*(2,80) = 1.18, *p* = .314, partial η^2 =.03.

Crucially, the presence of gesture, both the combination of iconic and deictic gestures, as well as beat gestures, accompanying verbal route directions did not enhance either the detail or gist of participants' reporting of route direction information during verbal recall. The similarity in both the accuracy and gist of route information recall across conditions indicates that the visual and motor cues provided by gesture did not enhance listener comprehension and memory for verbal recall above and beyond the verbal route directions.

Physical route navigation. To determine the influence of gesture on listeners' successful physical route navigation, two ANOVAs were carried out on 1) the number of decision points navigated by participants and 2) critical deviation scores (i.e., the point at which participants made a critical deviation from the target path), with gesture condition entered as the between-subjects factor and participant SBSOD (centered at the mean) entered as a predictor. The pattern of findings was the same for each ANOVA. For the number of decision points navigated, there was no main effect of gesture condition, $F(2,80) = 0.02$, $p = .979$, partial $\eta^2 < .01$ (see Table 1). There was a main effect of SBSOD, $F(1,80) = 5.23$, $p = .025$, partial $\eta^2 = .06$, such that as SBSOD increased the number of decision points navigated by participants also increased. There was no significant interaction between SBSOD score and gesture condition, $F(2,80) = 0.50$, $p = .607$, partial $\eta^2 = .01$. For the point at which participants made a critical deviation from the target path, there was also no significant main effect of gesture condition, $F(2,80) = 2.65$, $p = .077$, partial $\eta^2 = .06$ (See Table 1). There was a main effect of SBSOD, $F(1,80) = 9.84$, $p = .002$, partial $\eta^2 = .11$, such that as SBSOD increased the point at which participants made a critical deviation from the target path was further along the route. There was no significant interaction between SBSOD score and gesture condition, $F(2,80) = 1.84$, $p = .165$, partial $\eta^2 = .04$.

Our finding that the gestures accompanying route directions through a large-scale environment did not enhance adults' recall of the route replicates previous research involving a small-scale spatial array (Austin & Sweller, 2014). While these are the first studies examining the effect of gesture on recall, the findings are inconsistent with findings from several other studies that found gesture enhanced recall of factual sentences and short stories (Cohen & Otterbein, 1992; Feyereisen, 2006; Thompson, Driscoll, & Markson, 1998; Woodall & Folger, 1981). It is possible that gesture does not enhance listeners' recall for spatial information, only for narrative, abstract or conceptual information. Given gesture's capacity to allow for the visual representation of spatial route information, however, this possibility is difficult to explain. Alternately, it is possible that the similarity in recall across conditions was due to features of the experimental design, with a relatively low degree of new or unique information conveyed through gesture. Supporting this possibility, examination of the stimulus video for the iconic-deictic gesture condition revealed 71% of phrases (29 of 41 phrases) were accompanied by gestures which did not convey any additional information beyond the speech content. In other words, they were redundant (McNeill, Cassell, & McCullough, 1994).

Existing research has demonstrated that redundant and emphasizing gestures (e.g., beat gestures) enhance recall of non-spatial content, possibly by bringing a visual and motor component to verbal information processing (Cohen & Otterbein, 1992; Feyereisen, 2006; Mayer, 2009; Paivio, 1990; Thompson et al., 1998; Woodall & Folger, 1981). For listeners in the current study, processing route direction information through speech and gesture may have altered information processing from verbal only to a combination of verbal, visual, and motor processing. However, as the same visual and motor information was conveyed in speech as in gesture, this change in information processing may not have led to a reduction in the information processing demands above and beyond the processing of verbal only information. In other words, the large degree of overlap in information may not be more beneficial for memory processes than speech alone when an adequate mental representation can be created based on one source of information (i.e., spoken route directions). As such, redundant gestures may not benefit listeners' memory processes for route direction information: the mental representation generated by processing verbal route directions and verbal + redundant gestures is too similar. Conversely, non-redundant gestures supplement information conveyed in speech by communicating information not present in speech content (McNeill et al., 1994).

Non-redundant gestures may have communicative benefits beyond that of redundant gestures because instead of a single information unit being conveyed through two semantic systems (speech and gesture), two information units are conveyed through the two semantic systems. Non-redundant gesture requires listeners to create two distinct mental representations and resolve the information conflict by creating referential connections and, therefore, requires extra processing (Mayer, 2009; McNeill et al., 1994; Paivio, 1990; Schüler et al., 2015). As such, non-redundant gestures may enhance listeners' memory for route directions to a greater extent than redundant gestures.

Route directions tasks require individuals to process sequential spatial information, and as such the volume of information to be recalled may place demands on individuals' cognitive resources (Allen, 2000). As previously mentioned, cognitive abilities (e.g., spatial ability, verbal ability) influence spatial information processing (Vanetti & Allen, 1988; Wen et al., 2011; Wochinger & Boehm-Davis, 1995). It is possible then, that the presence of non-redundant gesture in communication may have different effects for individuals with different cognitive abilities (i.e., spatial ability, vocabulary, processing speed, memory, cognitive load) due to the additional processing load (McNeill et al., 1994). If the cognitive processes and mechanisms involved in creating a mental representation based on speech and gesture provide one source of individual differences, then it is important to examine the relationship between cognitive abilities and the effects of gestures accompanying speech for listeners.

Experiment 2

In Experiment 2 we extended the findings of Experiment 1 in two ways. First, we tested the influence of gesture redundancy and non-redundancy on listeners' recall. In Experiment 1, 71% of the iconic and deictic gestures accompanying the route description were redundant gestures: that is, they accompanied the verbal description but did not extend upon it. In practice, redundancy in communication enables listeners to reconstruct a partially transmitted message, respond to unexpected situations, missing signs, and to correct transmission errors (Frank, 2004). In an experimental design with a clear verbal description, however, the repetition of the verbal message through gesture may not have enhanced route recall because an adequate mental representation could be created based on one source of information only (i.e., spoken route directions). In Experiment 2, therefore, we presented both redundant and non-redundant gestures accompanying partially complete route directions. Second, we included additional measures of participants' spatial ability, language skill, processing speed, memory span, and perceived cognitive load to examine if the presence of non-redundant gesture in communication has different effects for individuals with different cognitive abilities. We expected that individual differences in cognitive ability would lead to differences in spatial information encoding and recall, such that better cognitive abilities would enable participants to encode and recall spatial information conveyed verbally and non-verbally.

Method

Participants

Participants included 125 adults recruited from introductory and second-year psychology units at Macquarie University. There were 63 males and 62 females, and participants ranged in age from 18 to 52 years (*M* = 22.86, *SD* = 7.16). This study was approved by the Macquarie University Faculty of Human Sciences, Human Research Ethics Committee (HREC). Participants were given an information sheet and consent form indicating the purpose and procedure of the study. Participants were given course credit for participating.

Design

There were two independent variables each with two levels (Gesture Type: iconic-deictic gesture, no gesture; and Script Completeness: complete, incomplete) and two dependent variables (verbal recall and physical route navigation). In this study, the spoken route directions were either complete (i.e., verbally mentioning the direction of a turn) or incomplete (i.e., not mentioning the direction of a turn), and the combination with gesture results in either redundant gestures (e.g., verbal left turn is accompanied by a ‘left turn gesture”) or non-redundant gestures (e.g., the ‘left turn’ gesture provides the information missing from the speech content). As such, participants were randomly allocated to one of four conditions: complete script no gesture (n = 32), complete script iconic-deictic gesture (n = 31), incomplete script no gesture (n =31), and incomplete script iconic-deictic gesture (n =31). Next, all participants were presented with a video in which an adult male provided a verbal description of a target path in and around an unfamiliar building on campus and, depending on assigned condition, accompanying gestures.

Last, all participants were asked to complete measures of spatial ability, language skill, processing speed, memory span, perceived cognitive load and building familiarity.

Materials

Instructional video. Four videos were created of an actor conveying the same target path that had been used in Experiment 1. Consistent with Experiment 1, the videos were presented on a screen measuring 51cm width x 29cm height (20.1 x 11.4 inches). The actor appeared in the center of the screen facing forward. Participants sat approximately 50cm (19.7 inches) from the screen. Participants in the complete script no gesture condition and the complete script iconic-deictic gesture condition were presented with a video containing the same verbal description of the target path[2] and depending on assigned condition, no accompanying gestures or the same accompanying gestures as those presented to the iconic-deictic gesture condition in Experiment 1. Given that the Experiment 1 video for the iconic-deictic gesture condition contained a large degree of redundant information, an alternative video for an iconic-deictic gesture condition was created of the same target path used in Experiment 1. This involved removing information from speech that was conveyed in gesture so that the information conveyed in gesture was non-redundant for all phrases. For example, the Experiment 1 target path script contained the statement “and turn left” (narrator points left as the words “turn left” are verbalized) becomes “and then you turn” (narrator points to the left as the words “you turn” are verbalized) in the incomplete script (see Appendix B for the incomplete script). Participants in the incomplete script no gesture condition and the incomplete script iconic-deictic gesture condition were presented with a video containing the incomplete verbal description of the target path and

[2] With the exception that the word “aqua” was changed to “white” (see Appendix B for script).

depending on assigned condition, no accompanying gestures or the same gestures as those presented to the iconic-deictic gesture condition in Experiment 1. Prescribed gestures for the complete and incomplete iconic-deictic gesture conditions were performed at the same set points as in Experiment 1 within the verbal script for each video. Participants in the complete and incomplete script no gesture conditions were presented with a video containing only the verbal description of the target path while the narrator's hands remained still. Given that in Experiment 1 we found no difference in the effect of non-meaningful gestures (beats) vs meaningful gestures (iconic/ deictic) accompanying route information on verbal recall and physical route navigation, the non-meaningful gesture condition was not included in Experiment 2.

Measures of spatial ability. Spatial ability was assessed using the SBSOD described in the Method section of Experiment 1. In addition, spatial ability was also assessed using Direction Estimates, a measure of spatial orientation adapted for the purposes of this study from Montello, Richardson, Hegarty, and Provenza (1999). Participants were given a circular pointing dial to make directions estimates, in the form of a smooth piece of cardboard with 0-360 marked along a radius line with a rotating arrow. Participants were asked to stand facing the center of the door and asked to "move the arrow to point it in the direction you estimate the [location] to be in from this position, facing in this direction". Participants were given 5 locations for which to estimate directions for from that position. Participants were then asked to imagine they were standing at a specified location on campus and make another 5 direction estimations as if they were standing in that location. Locations were selected such that they ranged in directions from both positions. Participants were asked to return the arrow to 0 (facing themselves) before the next location was given. In order to measure participant accuracy, a set of direction judgments for the locations was developed from which to calculate difference scores. Direction judgments were created by plotting the center of each location to be estimated on a map of the campus and measuring the degree (0-360) of each location from either the experimental room or the imagined position. Higher difference scores reflect a greater difference between participant estimation and the direction judgment.

Measures of verbal ability. The Peabody Picture Vocabulary Test Version 4 Form B (PPVT) was used to examine participants' receptive language skills (Dunn & Dunn, 1997). The PPVT comprises of 228 words grouped into 19 sets of 12 where examinees are required to select the most appropriate picture from an array of 4 pictures corresponding to a verbally presented word. Testing ceases once they have completed all the words or until they have made 8 consecutive errors. The PPVT does not contain any spatial terms (e.g., up, down, through, left, right). The PPVT-4 has internal consistency of .97 (Dunn & Dunn, 1997).

Measure of processing speed. Participants completed the written form of the Symbol Digit Modality Test (Smith, 2007) which involves substituting symbols for numbers. Participants have 90 seconds to pair specific numbers with the geometric figures provided. A higher score indicates greater number of correct symbol to number substitutions. This measure has an internal reliability of .79.

Measure of memory span. Participants completed the Auditory Number Span (ANS) task which consists of 24 series of number spans ranging from 4 digit spans to 12 digit spans (Ekstrom, French, Harman, & Dermen, 1976). A higher score indicates greater number of number series recalled correctly. This measure has an internal reliability of .63.

Measure of perceived cognitive load. Participants completed The Cognitive Load Questionnaire, which consists of 13 statements about participants' intrinsic, extraneous, and germane cognitive load on a scale of 0 (not at all the case) to 10 (completely the case; Leppink, Paas, van Gog, van der Vleuten, & van Merriënboer, 2014). A higher Cognitive Load score indicated greater invested mental effort. This scale has an internal reliability of .88 for intrinsic cognitive load, .79 for extraneous cognitive load, and .93 for germane cognitive load. For the current study this scale has an internal reliability of .61 for intrinsic cognitive load, .78 for extraneous cognitive load, and .87 for germane cognitive load.

Building familiarity measure. Participants' familiarity with the building was assessed using the building familiarity measure described in the Method section of Experiment 1.

Procedure

The procedure for Experiment 2 was identical to the procedure used in Experiment 1, with the exception that the additional cognitive measures were administered following video presentation and recall. Following physical route navigation recall of the target path, participants then completed the SBSOD, the PPVT language task, the Direction Estimate task, the cognitive load questionnaire, the ANS memory task, the SDMT processing speed task, and the building familiarity survey, with the order of presentation counterbalanced between participants. The entire procedure took 45 to 50 minutes per participant, depending on the length of each participant's response. All participants completed the task in one session.

Coding and Reliability

Coding of participants' verbal and gestural responses followed the same protocol as that used in Experiment 1, regardless of group allocation. That is, all transcripts were coded according to the complete route direction description regardless of whether participants received spatial route direction information through speech only, through both speech and gesture, or not at all. To determine inter-rater reliability, two coders independently coded 25% of the transcript and video data. Only the first coder was aware of the purpose of the task. Inter-rater reliability was evaluated through single-rater intraclass correlations (ICCs), with a consistency model. For speech coding during verbal recall, intraclass correlations were obtained for total locations ($ICC = .999$, $p < .001$), total movements ($ICC = .999$, $p < .001$), total descriptions ($ICC = .991$, $p < .001$), total recall ($ICC = 1.000$, $p < .001$), and total gist ($ICC = .998$, $p < .001$). For gesture coding during verbal recall, intraclass correlations were obtained for deictic gesture ($ICC = 1.000$, $p < .001$), iconic gesture ($ICC = 1.000$, $p < .001$), beat gesture ($ICC = 1.000$, $p = .001$), and metaphoric gesture ($ICC = 1.000$, $p < .001$). For physical navigation recall coding, intraclass correlations were obtained for decision point score ($ICC = .997$, $p < .001$), and critical deviation point score ($ICC = .972$, $p < .001$). Across all categories scores were above .900, and the first coder, therefore, coded the remainder of the transcripts and videos

Results and Discussion

To examine the effect of different kinds of gestures on recall of route directions, participants' verbal and non-verbal recall of route direction information was first analyzed for the accuracy of different kinds of route information (i.e., location, movement, description) and then for the gist of the route, and finally for the effect of gesture on participants' physical route navigation. As noted above, the study was conducted on campus and therefore some participants may have had a degree of familiarity with the building in which the study was carried out. A one-way analysis of variance (ANOVA) with gesture condition as the between subjects factor was carried out to examine differences in participants' familiarity with the building. The analysis revealed no significant difference between the complete script no gesture condition ($M = 33.42$, $SD = 23.70$), complete script iconic-deictic gesture condition ($M = 27.77$, $SD = 27.37$), incomplete script no gesture condition (*M* = 27.87, *SD* = 21.64), incomplete script iconic-deictic gesture condition (*M* = 32.94, *SD* = 26.61) in participants' building familiarity ($F(3,120) = 0.48$, $p = .698$, partial $\eta^2 = .01$).

Accuracy of verbal recall. Participants' location, movement, and description item recall was transformed into percentages and entered into a 2 (Gesture Type: no gesture or gesture) x 2 (Script Completeness: complete or incomplete) x 3 (Feature Type: locations, movements, or descriptive) mixed design ANOVA, with gesture type and script completeness as the between-participants factors and feature type as a within-participant factor. Participant SBSOD was centered at the mean and entered as a predictor. Participant PPVT, Direction Estimate, SDMT, ANS, and Cognitive load scores were also entered as predictors separately for each ANOVA, however, as the pattern of results was unchanged, only the SBSOD analysis is reported here (all analyses available from authors on request). For analyses where the assumption of sphericity was violated and Greenhouse-Geisser ε was greater than .75 and therefore too conservative, Huynh-Feldt ε adjusted results are reported (Field, 2009). Significant effects were followed up with pairwise comparisons (simple effects analyses) with a Bonferroni adjustment to *alpha* values ($p < .017$) with unadjusted *p* values reported.

The analysis revealed no main effect of gesture type, $F(1,116) = 1.29$, $p = .259$, partial $\eta^2 = .01$, or script completeness, $F(1,116) = 2.47$, $p = .118$, partial $\eta^2 = .02$, and no gesture type by script completeness interaction, $F(1,116) = 1.85$, $p = .177$, partial $\eta^2 = .02$. As in Experiment 1, however, there was a main effect of feature type, $F(1.48, 171.10) = 15.53$, $p < .001$, partial $\eta^2 = .12$. Examination of simple effects revealed that while more location items were recalled than movement items, $F(1,232) = 69.45$, $p < .001$, partial $\eta^2 = .23$, and more descriptive than movement items $F(1,232) = 11.99$, $p = .002$, partial $\eta^2 = .34$, there was no difference in participants' recall for location and descriptive items $F(1,232) = 1.34$, $p = .745$, partial $\eta^2 = .01$. There was also a main effect of SBSOD, $F(1,116) = 14.07$, $p < .001$, partial $\eta^2 = .11$, such that as SBSOD increased, recall also increased. There was a significant interaction between feature type and script completeness $F(1.48, 171.10) = 5.94$, $p = .007$, partial $\eta^2 = .05$, such that participants presented with the complete script recalled more movement items than participants presented with the incomplete script $F(1,116) = 12.25$, $p = .001$, partial $\eta^2 = .10$, but there was no difference between the two scripts in the number of location or description items recalled (both *p*s > .05).

There was no significant interaction between feature type and gesture type, $F(1.48, 171.10) = .83$, $p = .408$, partial $\eta^2 = .01$, and no significant interactions between SBSOD and gesture type, script completeness, or feature type (all *p*s > .05). There was, however, a significant three-way interaction between feature type, script completeness and gesture type, $F(1.48, 171.10) = 3.50$, $p = .046$, partial $\eta^2 = .03$ (see Fig. 3). Simple effects analyses revealed that when no gesture accompanied route directions, recall of location items ($F(1,116) = 5.91$, $p = .017$, partial $\eta^2 = .05$) and movement items ($F(1,116) = 16.33$, $p < .001$, partial $\eta^2 = .12$) was greater when presented with the complete script than the incomplete script, whereas no difference was found between the two scripts for description items ($F(1,116) = 0.11$, $p = .741$, partial $\eta^2 < .01$). Conversely, when gesture accompanied route directions, there was no difference in recall between the complete and incomplete scripts for location, movement, or description items (all *p*s > .05).

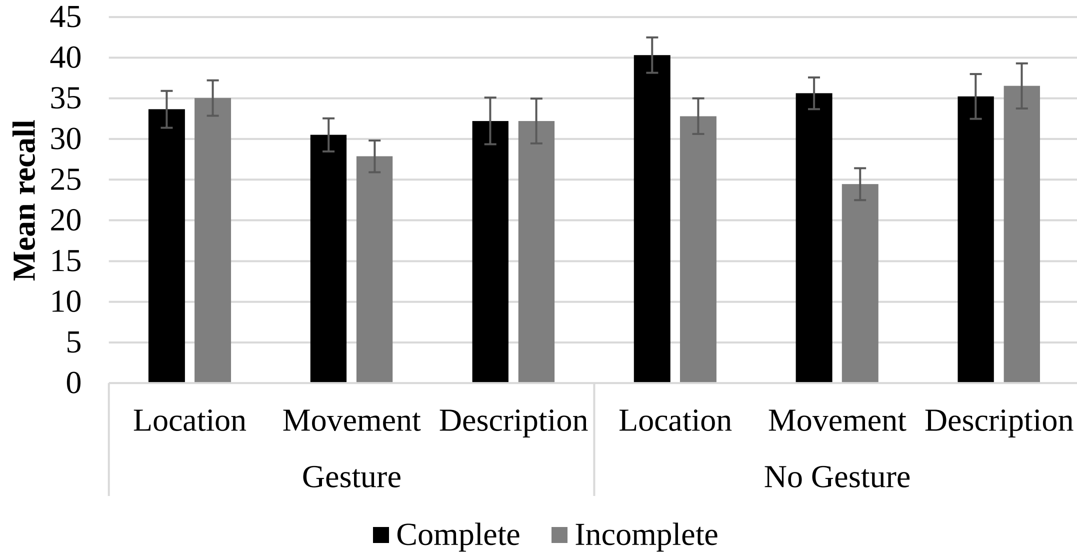

Fig. 3. Mean scores for the recall of location, movement and description items for the complete and incomplete scripts for gesture and no gesture conditions.

In summary, as expected, when route directions were conveyed through speech alone, participants recalled more location and movement information when directional information was conveyed in speech than when directional information was missing from speech content. Crucially, when gestures did accompany verbal route directions, participants recalled as much location, movement, and descriptive information when additional directional information was conveyed through gestures (i.e., non-redundant) as when the information was conveyed through speech and gesture (i.e., redundant). This difference indicates that listeners created a mental representation of the visual and motor cues provided by non-redundant gesture and then integrated this via referential connections with the mental representation of spoken information to form a complete mental representation of the route. This result reflects adults' ability to integrate, process, and recall information conveyed through multiple modalities.

Gist of verbal recall. Participants' gist recall was analysed in a 2 (Gesture Type: no gesture or gesture) x 2 (Script Completeness: complete or incomplete) between-subjects design ANOVA with participant SBSOD (centred at the mean) entered as a predictor. The analysis revealed no main effect of gesture type, $F(1,116) = 0.42$, $p = .518$, partial $\eta^2 < .01$, or script completeness, $F(1,116) = 3.89$, $p = .051$, partial $\eta^2 = .03$. See Table 2 for descriptive statistics. There was a main effect of SBSOD $F(1,116) = 18.38$, $p < .001$, partial $\eta^2 =.14$, such that as SBSOD increased participant gist recall also increased. There was no significant interaction between gesture type and script completeness in the amount of gist verbally recalled, $F(1,116) = 2.72$, $p = .102$, partial $\eta^2 = .02$, and no significant interactions involving SBSOD (all *p*s > .05).

Table 2

Estimated marginal mean (and Standard Error) Gist, Decision Point and Critical Deviation Point recall by Script Redundancy and Gesture Condition

	Complete Script		Incomplete Script	
	No Gesture	Gesture	No Gesture	Gesture
Gist	20.17 (0.98)	17.90 (1.02)	16.59 (0.98)	17.58 (0.98)
Decision Points	15.02 (0.82)	12.01 (0.85)	13.65 (0.82)	11.96 (0.82)
Critical Deviation Point	9.09 (0.84)	7.66 (0.87)	7.52 (0.84)	4.85 (0.84)

Note. Standard Errors appear in parentheses

Physical route navigation. To determine the influence of gesture on listeners' successful physical route navigation, two ANOVAs were carried out on 1) the number of decision points navigated by participants and 2) critical deviation scores (i.e., the point at which participants made a critical deviation from the target path), with gesture condition entered as the between-subjects factor and participant SBSOD (centered at the mean) entered as a predictor. The analysis revealed a main effect of gesture type, F(1,116) = 8.09, p = .005, partial η^2 = .07, such that more decision points were navigated when no gesture accompanied the route directions than when gesture accompanied the route directions (See Table 2). There was no main effect of script completeness, F(1,116) = 0.73, p = .395, partial η^2 = .01, and no significant interaction between gesture type and script completeness in the number of choice points navigated, F(1,116) = 0.65, p = .423, partial η^2 = .01. There was a main effect of SBSOD F(1,116) = 6.63, p = .011, partial η^2 =.05, such that as SBSOD increased the number of decision points navigated also increased. There was a significant interaction between SBSOD and gesture type, F(1,116) = 4.59, p = .034, partial η^2 = .04, such that the effect of SBSOD score was greater for decision point navigation when gesture accompanied route descriptions than when no gesture was present. There was no significant interaction between SBSOD and script completeness, and no significant three-way interaction between script completeness, gesture type, and SBSOD (both ps > .05).

The point at which participants made a critical deviation from the route was similarly entered into a 2 (Gesture Type: no gesture or gesture) x 2 (Script Completeness: complete or incomplete) between-subjects design ANOVA with participant SBSOD (centered at the mean) entered as a predictor. The analysis revealed a main effect of gesture type, F(1,116) = 5.89, p = .017, partial η^2 = .05, such that participants navigated more of the route before making a critical deviation when no gesture accompanied route directions than when gesture accompanied route directions. There was a main effect of script completeness, F(1,116) = 6.73, p = .011, partial η^2 = .06, such that participants navigated more of the route before making a critical deviation when presented with the complete script than when presented with the incomplete script (See Table 2). There was no significant interaction between gesture type and script completeness in the critical deviation point during navigation, F(1,116) = 0.53, p = .467, partial η^2 = .01. There was no main effect of SBSOD ($F(1,116) = 1.50$, $p = .223$, partial $\eta^2 = .01$) and no significant interactions involving SBSOD (all *p*s > .05). During physical route navigation, getting further along the route before making a critical deviation off the route indicates better recall of the target path. In this case, adults successfully navigated more of the route before making a critical deviation when route directions were not accompanied by gesture than when accompanied by gestures. Furthermore, adults were able to physically navigate more of the route when directional information was included in the route directions than when route directions did not include directional information.

The results of Experiment 2 replicate the differences in location, movement and descriptive item recall found in Experiment 1. They also extended our earlier findings to non-redundant gestures. When directional information was missing from speech and there were no accompanying gestures, adults verbally recalled fewer route details (i.e., location and movement items). When gestures accompanied route directions however, adults' verbal recall was equivalent regardless of whether the spatial information was conveyed through speech and gesture (i.e., redundant gestures) or gestures alone (i.e., non-redundant). Conversely, physical route navigation was less successful when gestures accompanied route direction information than when provided with verbal only route directions. Adults' physical route navigation was more successful when directional information was conveyed through speech than when directional information was conveyed through gesture alone.

To date, the impact of speakers' gestures (redundant and non-redundant) on listener recall during spatial communication has been somewhat overlooked. There is some evidence that speakers' redundant gestures enhance listener recall of spatial route information during early childhood. For example, pre-school aged children who were presented with either beat gestures or a combination of gestures to accompany verbal route directions through a small-scale spatial array recalled more than children presented with spoken only route directions (Austin & Sweller, 2014). Gestures did not enhance adults' recall of the same route, however. The authors speculate that this finding might relate to the redundancy of the information presented through gesture, as redundant gestures accompanied speech (Austin & Sweller, 2014). To test this argument, the current study manipulated information redundancy directly: finding that only non-redundant gestures enhanced adults' recall of large-scale route directions. Such gestures may have facilitated the adult participants' encoding and recall of spatial information in a way that was not needed when the information is redundant. Indeed, for verbal recall, information could be presented verbally and/ or nonverbally without influencing recall. For physical navigation, information presented verbally was most effective but nonverbal information was still useful in the absence of verbal information. This finding demonstrates that speakers' gestures provide a valuable source of information about environmental space to adults as well as children, particularly when the spoken message is incomplete.

General Discussion

The ability to successfully follow route directions requires listeners to construct an imagined mental representation of the space based on the speakers' communication of location, movement, and descriptive information (Allen, 2000). While speakers use both verbal and non-verbal means to convey spatial information such as route directions, including gestures, little is known about the influence of gesture on recall. Across two experiments, we examined whether gestures accompanying route directions through a large-scale environment benefit listener recall. In Experiment 1, the gestures accompanying route directions either primarily expressed the same information as the speech they accompanied (i.e., they were redundant), or had no apparent semantic connection with speech (i.e., beat gestures). Neither meaningful (iconic and deictic) gestures nor non-meaningful (beat) gestures enhanced participants' route recall, relative to no gesture. This was true for both verbal recall of the route and physical route navigation. It is possible that despite being processed through multiple modalities (i.e., verbal, visual and motor), messages accompanied by gesture only leave a richer trace in memory when the gestures convey information beyond speech content (i.e., non-redundant gestures).

Experiment 2 addressed whether non-redundant gestures accompanying route directions through a large-scale space benefit listener recall. As such, the gestures accompanying route directions in Experiment 2 were manipulated such that some expressed the same information as the speech they accompanied (i.e., they were redundant), and some conveyed information beyond the speech content (i.e., they were non-redundant). To achieve this we removed information from speech content. For example, the phrase "turn" replaced "turn left", with both accompanied by a pointing to the left gesture. In the former only the gesture conveys the directional information, while in the latter directional information is conveyed through both speech and gesture.

Crucially, when directional information was presented through gesture, listeners verbally recalled just as much location, movement and descriptive information when directional information was conveyed in both speech and gesture (i.e., the gestures were redundant) as when that information was missing from speech content and only presented through gesture (i.e., the gestures were non-redundant). Unsurprisingly, when processing information conveyed through speech alone, listeners' verbal recall of location and movement information was poorer when directional information was missing from speech. Despite differences in gesture and script completeness, the gist of listeners' verbal recall was similar across conditions. The similarity in recall between redundant and non-redundant gestures suggests that the additional information processing of visual and motor information provided by gestures enhances recall when information is missing from speech content. This in turn implies that verbal messages about space that are accompanied by gestures are processed through multiple modalities. These findings are important because they reflect adults' ability to integrate, process and recall spatial information conveyed through multiple modalities and highlights the role gestures play in facilitating spatial communication when spoken messages are incomplete.

Across both studies and irrespective of condition, adults verbally recalled more location than movement or description information, and more movement than description information. In addition, adults' spatial ability had an effect on spatial recall. Individuals with higher spatial ability verbally recalled more (details and gist) than those with lower levels of spatial ability. In particular, listeners' spatial ability had a greater effect on the verbal recall of location and movement information than description information. Taken together, these findings suggests two things: firstly, that listeners most strongly attend to the aspects of spoken route directions which provide salient contextual cues (i.e., location information) and prescribed movement information to enable them to verbally recall the route, and secondly, that an individual's spatial ability influences the relationship between encoding and recalling elements of spatial information (i.e., locations and movements) with higher spatial abilities facilitating the processing and recall of spatial location and movement information. In sum, listeners' spatial ability influences verbal recall of spatial information. Verbal recall is important for verbal clarification of route comprehension, but given that the purpose of route communication is to enable listeners to successfully travel from A to B, successful physical route navigation is arguably the most important indicator of recall for the role of gesture in spatial communication for listeners.

Successful route navigation requires listeners to match the mental representation they generated at encoding to the perceptual experience of the environment (Vanetti & Allen, 1988; Wochinger & Boehm-Davis, 1995). It was expected that gestures accompanying route directions would lead to more of the route being physically navigated than route directions conveyed through speech alone. In contrast to expectations, Experiment 2 found both redundant and non-redundant gestures had a detrimental impact on physical route navigation. Physical navigation was more successful when route directions were conveyed through speech alone (i.e., both no gesture conditions), and when directional information was included in the spoken message (i.e., redundant script no gesture condition). For example, participants presented with gestures (redundant and non-redundant) accompanying route directions made critical deviations from the target path sooner and more frequently than individuals presented with no gesture. It is possible that deeper processing and more elaborate mental representations of route direction information elicited by speech and gesture may have led to a discrepancy between listeners' imagined mental representation of the environment and the actual physical experience when navigating the route. For listeners presented with gesture, resolving the discrepancy between an imagined mental representation and the physical environment may require greater cognitive work, thus leading to less successful route navigation.

Interestingly, Experiment 2 also found that listeners with higher spatial ability successfully navigated more of the route, particularly when gestures (redundant and non-redundant) accompanied route directions than when no gestures accompanied route directions. Having higher spatial abilities may then help listeners by resolving the discrepancy between the imagined and actual route environment, influencing the resources available for the transient storage demands of the task and leading to more successful route navigation. Importantly, for listeners' route navigation to be successful, the presence of directional information in spoken route directions is essential.

As mentioned previously, only one study has examined the role of gestures accompanying route direction communication for listeners (Austin & Sweller, 2014). Austin and Sweller (2014) found that adults presented with gestures accompanying route directions through a small-scale environment did not verbally recall more than those presented with no gestures accompanying route directions. Consistent with this previous finding, Experiment 1 found redundant gestures (meaningful and non-meaningful) did not enhance adults' recall of route direction information through a large-scale environment. Experiment 2 found evidence that non-redundant gestures (a combination of iconic and deictic) enhanced recall for large-scale route directions, suggesting that listeners attend to salient verbal (i.e., location and movement information) and nonverbal contextual cues (i.e., gestures). Together these findings suggest that gestures which replicate the information conveyed in speech (i.e., redundant gestures) did not enhance verbal recall for spatial content, but that the benefit of gestures may only be apparent when gestures convey additional information to the spoken message (i.e., non-redundant gestures). Importantly, the current study provides evidence that speakers' non-redundant gestures convey important contextual cues to listeners during spatial communication, providing listeners with a valuable source of information about a spoken spatial message.

While Austin and Sweller (2014) examined the influence of speakers' gestures on listeners' verbal recall, research has not yet examined the effect of speakers' gestures on listeners' physical route navigation. For listeners, route navigation requires matching their imagined mental representation of the route (based on the speaker's spoken message) to their perceptual experience when navigating the environment (Vanetti & Allen, 1988; Wochinger &

Boehm-Davis, 1995). As mentioned previously, Experiment 2 found adults successfully navigated more of the route when presented with a complete verbal description of route directions without accompanying gestures. This is the first study examining the effect of gesture on non-verbal recall of spatial information and suggests that speakers' gestures may interfere with listeners' ability to recall route information during physical route navigation. The current study extends existing research, providing evidence that adults integrate speakers' speech and gesture at encoding during spatial communication. Furthermore, the current study implies that the beneficial effect of gesture accompanying spatial content may depend on how the information is to be recalled.

Despite existing only momentarily in the external environment, gestures ground communication in the environment (Tversky, 2011; Wilson, 2002). The current studies advance our understanding of how listeners process information from multiple sources (i.e., speech and gesture). For listeners, redundant and non-redundant gestures provide visual and motor information, facilitating the creation of a mental representation which is then integrated with a mental representation of the speech content (Mayer, 1997; Piavio, 1990). The dual processing of spatial information through speech and gesture (i.e., redundant and non-redundant) may benefit listeners' cognitive processes by providing a memory backup. That is, if one mental representation is forgotten, then the other may still be accessible in memory. Dual processing may also reduce the information processing demands of verbal information and increasing the cognitive resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992). In other words, spoken messages accompanied by gestures reduce the cognitive resources needed by the speech comprehension process, making more resources available for creating and maintaining mental representations, thereby facilitating verbal recall of route direction information (Cameron & Xu, 2011). Conversely, resolving the discrepancy between listeners' mental representation and the actual environment reduces the cognitive resources available for maintaining mental representations, thereby hindering non-verbal recall of route direction information. For listeners, the potential beneficial effect of gesture at encoding on the reduction of processing demands and resulting increase in resources for spatial task demands may depend on how the information is to be recalled.

Limitations and Future Research

The current study found that meaningful gestures (a combination of iconic and deictic gestures) facilitated verbal recall for large-scale route directions when information was missing from the spoken message. When information was not missing from speech, however, these same meaningful gestures had no influence on verbal recall. Unfortunately, the overlap between redundant and non-redundant conditions did not allow for a clear comparison examining the effect of gesture redundancy on listener recall. As previously mentioned 29% of gestures for the iconic-deictic gesture condition accompanying route directions in both Experiment 1 and the redundant script in Experiment 2 were not redundant. Despite this overlap in redundancy, these findings provide further evidence that gesture provides listeners with a valuable source of information about a speaker's message.

Experimental conditions regarding the recall of information in research examining the effect of gesture on spatial route direction information are worth noting. In the current study, the instructions given to participants before watching the video were intended to ensure that participants attended to the video. These instructions however, emphasized that the need to attend was due to a verbal recall task that was to follow the video presentation. It is possible that results may have differed if the task instructions had emphasized the physical route navigation task. In addition, according to Gricean conversation maxims principle of quantity, the least amount of information is sufficient (Grice, 2000). Our instructions asked participants to include as much detail as possible in their verbal description and to describe the route exactly. The implication from these instructions was to relay as much detail, including descriptions, as participants could remember. Our instructions may have asked for more than the principle requires as a stronger test of recall.

Together with speech, gestures can facilitate communication and cognition for both speakers and listeners. The current study demonstrates the communicative importance of a speaker's gestures depends on the quality of the accompanying speech and how the information is recalled (verbal or physical route navigation). The conflicting evidence across domains in the existing literature, regarding the role of redundant and non-redundant gestures in communication for listeners, requires further investigation. It is important to examine the role of gestures which convey information consistent with speech content (i.e., redundant) and gestures which go beyond speech content (i.e., non-redundant), for listeners in the context of everyday interactions involving both spatial and non-spatial communication. Future research could examine the effect of redundant and non-redundant gestures accompanying spatial and non-spatial task information on listener recall, both verbal and nonverbal. In terms of effective communication, clarifying the link between the information conveyed in speech, in relation to information conveyed in gesture, is important for developing an understanding of gesture as a source of information for listeners.

Gesture can have different effects at different times throughout the lifespan and may be particularly important when cognitive abilities such as language, memory, and information processing, decline during older adulthood (Austin & Sweller, 2014; Postma, van Oers, Back, &

Plukaard, 2012; Wochinger & Boehm-Davis, 1995). Consistent with this, existing research suggests that older adults are poorer at navigation than younger adults, with age-related differences in global configuration (i.e., locating landmarks) and in judgments of indirect spatial sentences (Gyselinck, Meneghetti, Bormetti, Orriols, Piolino, & DeBeni, 2013; Postma et al., 2012; Wochinger & Boehm-Davis 1995). It is important, therefore, to examine whether gestures accompanying spatial information enable older adult listeners to overcome cognitive deficits (i.e., language, memory, and processing speed; Postma et al., 2012; Wochinger & Boehm-Davis 1995). Future research could examine the effect of gesture accompanying route directions for older adults at different ages. In terms of development, establishing the link between gestures accompanying speech and task performance is important for developing an understanding of gesture as a source of information for listeners across the lifespan.

Implications and Conclusion

People of all ages and cultures produce gestures when they speak. Consequently, the meaningful integration of speech and gesture has implications for cognition and learning in a variety of applied domains. Gesture can be a low-cost tool that enables listeners to process and recall spatial messages, particularly when the spoken message is poor quality. In educational settings, educators might be encouraged or trained to produce effective gestures during professional development seminars. Specifically, the training might examine the spontaneous gestures educators already produce, and provide education and feedback on how their gestures might be adjusted to optimize their communicative value, and thus the benefit to their students. Therefore, teachers can use gesture to enhance fundamental aspects of their profession, including communication and the ability to instill a better understanding of abstract concepts in traditionally difficult domains such as language and spatial computation. When teachers must communicate size or direction in a way that is difficult to verbalize (e.g., when discussing multidimensional visualizations in science, or complex systems in design and technology), gesture can enhance students' cognitive processing of the spoken message.

Beyond the laboratory and educational settings, the findings from the current study can be applied in situations requiring individuals to convey spatial information when environmental factors such as noise make verbal communication difficult (e.g., construction/ building sites or farms). Communicating direction or orientation in a changing environment can be difficult to verbalize, e.g., when conveying the orientation of a wall to be built or how large objects should be placed. Gesture can facilitate employees' communication and cognitive processing of spoken messages. In these industries, gesture training might be incorporated into the initial formal training or work orientation, providing employees with understanding and feedback on how they can maximize the use of their hands in communication. Encouraging individuals to produce gesture when giving spatial directions or instructions can lead to better recall and performance of tasks for listeners, providing a protective factor against poor quality spoken messages.

The current findings suggest that for listeners, gestures are important when speakers' spoken messages are missing information. These results strongly support the view that information processed through verbal and non-verbal modalities benefits listeners by facilitating imagined mental representations, particularly when information is missing from the spoken message. These findings provide a greater understanding of the role gesture plays during communication for listeners, indicating that gesture is an integral part of communication when spoken messages are incomplete.

Chapter 5. General Discussion

This thesis aimed to extend previous gesture research (e.g., Allen, 2003; Austin & Sweller, 2014; Cassell et al., 2007; Sekine, 2009; So et al., 2012) by examining the relationship between speakers' speech and gestures when conveying spatial information. In addition, it also aimed to examine the effect of gestures accompanying spatial information on listeners' task performance. In addressing these aims, the thesis further contributes to our understanding of the role of gesture in communication by examining two specific functions of gestures for speakers and two for listeners. For speakers, the thesis examined the extent to which gestures either 1) helped speakers translate spatial knowledge into speech, and / or 2) eliminated the need to translate knowledge into speech (See Chapter 2). For listeners, the thesis investigated the extent to which gestures accompanying spatial information either 1) helped clarify the spoken message, and / or 2) served as an elaborate route direction encoding strategy, thereby facilitating spatial information recall during early childhood and adulthood (See Chapters 3 and 4).

Chapter 2 presented an empirical analysis of the types of speech and gestures preschoolers and adults produced when conveying large-scale route directions. Specifically, Chapter 2 explored developmental differences in the use of gesture, as well as the effect of task purpose on adults' use of gesture. This analysis demonstrated developmental differences in the use of gesture when conveying spatial information. For example, adults primarily produced pointing gestures when conveying route directions, while preschoolers produced both enacting gestures and pointing gestures. The analysis also revealed quantitative and qualitative similarities in gesture production regardless of the task purpose for adults. Chapter 3 illustrated that speakers' gestures (iconic, deictic, and beat) benefited preschoolers' verbal recall of route direction information, as well as their physical route navigation. Finally, Chapter 4 demonstrated that speakers' gestures benefited adults' verbal recall of route direction information, but only when the gestures presented information missing from speech content (i.e., the gestures were non-redundant). A different effect was found for physical route navigation, however. Speakers' gestures (both redundant and non-redundant) had a *detrimental* impact on listeners' physical route navigation, with adults deviating from the target path sooner when gestures accompanied route information.

Taken together, the findings of this thesis have significant implications for the field of gesture research, as they show that we use gesture to express spatial information and that our use of gesture changes with age. These findings further demonstrate that the expression of spatial knowledge accompanied by gesture production facilitates encoding and subsequent verbal recall for listeners during early childhood and for adults, and can ultimately influence successful task performance.

In order to fully explore the implications of the work that has been conducted, and discuss how future research can build upon the present findings, this chapter will be structured as follows. First, it will contain a discussion of gesture production, in light of the findings presented here, both in terms of development and task purpose. Then, it will move on to discuss the role of gesture accompanying speech for listeners during early childhood, particularly cementing the importance of gestures in the context of spatial communication and cognition. A discussion of how speakers' gestures benefit adult listeners and how cognitive abilities explain differences in the effect of gesture on task performance will be presented. Then it will move on to discuss the theory explaining the function of gesture during spatial task performance for both speakers and listeners. Limitations of the work presented here and proposals of areas for future research will then follow. This chapter will finish with general conclusions and a discussion of the broader context within which the work sits.

Speakers' Gesture Production During Spatial Knowledge Communication

The first aim of this thesis was focused on the production of gesture; namely to investigate the relationship between types of speech phrases and types of gesture during route direction communication for both young children and adults. This first aim was explored in Chapter 2 by assessing developmental and task purpose differences in the production of different types of gesture. In addition, Chapter 2 examined the relationship between types of gesture and types of speech phrase, as well as the information relationship between types of speech phrase and types of gesture.

Developmental similarities and differences in gesture production when conveying spatial knowledge. Perhaps one of the strongest claims in gesture research is that people produce gesture during the communication of spatial information (e.g., Alibali, 2005; Allen, 2003; Sauter et al., 2012; Sekine, 2009; Tversky, 2011). The results of the analysis between speech and gesture production presented in Chapter 2 confirmed previous work (Allen, 2003; Cassell et al., 2007; Sekine, 2009) and showed that gestures accompanied between 23% and 35% of speech phrases. Both children and adults primarily produced iconic (enacting) and deictic (pointing) gestures, as well as gestures that contained both iconic and deictic elements. Examination of developmental differences revealed that when describing route directions, children produced more iconic gestures than adults, but adults produced more deictic and iconic-deictic gestures than children. One possibility is that children's greater production of enacting gestures reflects a more concrete conceptualisation of space, possibly as a result of children's cognitive limitations (e.g., language, spatial perspective taking). Adults, with a wider vocabulary and greater capacity for spatial perspective taking generate a more abstract mental representation of space, which is reflected in the greater production of pointing gestures. It is also possible that differences in gesture production between children and adults stems from differences in pragmatic skill, especially how to interpret instructions (e.g., how participants perceive the listener's needs) (Holler & Bavelas, 2017; Kelly, 2001). In other words, the production of gesture might be influenced by higher-order pragmatic processes. In this way, children and adults may produce different gestures depending on their pragmatic skill and intent.

The developmental difference in gesture production is further supported by the finding that there was no quantitative or qualitative difference in gesture production between adults asked to describe the route and adults asked to convey the route in detail. This finding suggests that changing the task instructions does not change how adults use gesture to communicate about space. Existing research, which formed the basis of the work conducted here, has demonstrated that children and adults produce gesture during spatial communication (e.g., Allen, 2003, Cassell et al., 2007; Sekine, 2009, 2011). This thesis (Chapter 2), however, presented the first study examining developmental differences in the production of gesture during spatial information communication.

The information relationship between speech and gesture when conveying spatial knowledge. The results of the analysis between speech and gesture production presented in Chapter 2 showed that children used gesture to convey additional information not present in speech content more often than did adults, particularly for phrases without descriptive content. This developmental difference suggests that children may compensate for limitations in their verbal capacity by using their hands to extend the meaning of their verbal output. Closer examination of the types of gestures accompanying phrases with description (e.g., go down the wooden stairs) and without description (e.g., go down the stairs) revealed that children conveyed directional information (deictic) with their hands when phrases did not include descriptive content and depicted concrete images of referents (iconic) when phrases did include a description. In contrast, adults conveyed directional information (deictic gestures) with their hands both for phrases with description and without description. This finding suggests that while adults use their hands to convey directional information, children use their hands to enrich their verbal description of space and to convey direction information when not describing space.

Finally, the similarity in the degree of information conveyed through gesture beyond speech content, as well as adults' production of gestures accompanying phrases with and without description for the different task purposes, suggests that the purpose of the task does not change the way we communicate about space as adults. The work presented in this thesis (Chapter 2) is the first study examining developmental differences in the relationship between speech phrases and types of gesture and suggests that gesture is a reflection of spatial conceptualisation.

The work in this thesis (Chapter 2) demonstrated quantitative and qualitative differences in the use of gesture accompanying route direction communication between young children and adults. Existing literature has examined the qualitative relationship between speech and gesture during spatial communication (Cassell et al., 2007; Fricke, 2002; Kita, 2003; Levinson, 2003). For example, empirical work by Cassell et al. (2007) demonstrated a relationship between the form of gesture and the objects referred to in speech, suggesting a meaningful relationship between speech phrases and gestures. Together with the work presented in this thesis (Chapter 2), these findings suggest that gesture is an effective communicative tool in the communication of meaning (that is, the type of gesture and the information it conveyed is related to speech content) and that gesture might also be related in form to the speech content and spatial content accuracy (that is, the specific objects referred to in speech).

There are substantial differences in the use of gesture accompanying spatial task performance during early childhood compared with during adulthood, as discussed above. The next step in understanding the production of gesture during spatial communication is to examine the relationship between the form of gesture and the visual aspects of spoken referents. Such a comparison would allow for greater understanding of the commonalities between information conveyed through speech and information conveyed through gesture, by determining whether the conceptualisation of space is an accurate and meaningful reflection of cognitive changes. Future work, therefore, needs to determine whether the morphological features of gestures correspond to visual aspects of referents, thereby facilitating recall accuracy and whether these change during development.

Listeners' Use of Gesture During Spatial Knowledge Communication

Given the dyadic nature of face-to-face communication, a further aim of this thesis was to examine whether speakers' gesture production played a role in the encoding and subsequent recall of spatial information by listeners. This effect was confirmed in Chapters 3 and 4. Chapter 3 demonstrated that preschoolers recalled more of the route when gestures accompanied large-scale route directions than when presented with spoken only route directions. It was deemed important, therefore, to explore the potential benefit for adult listeners in Chapter 4. As for young children, adults' recall was enhanced when gestures accompanied spoken route directions that were incomplete.

Preschoolers' Use of Gesture Accompanying Spatial Information

Existing research has explored the effect of gesture accompanying speech on word and sentence recall of non-spatial content (e.g., Church et al., 2007; Igualada et al., 2017; Thompson et al., 1998). To date, only Austin and Sweller (2014) have examined the effect of gestures accompanying spoken messages for listeners who have not yet developed adult-like language skills (i.e., children aged 3 to 5 years) in the context of spatial communication involving a small-scale spatial task. Chapter 3 proposed a novel examination of the effect of gestures accompanying large-scale route directions on recall, as measured by task performance. It is widely acknowledged by gesture theorists that gestures play an important role in learning and communication (e.g., Alibali, 2005; Cartmill & Goldin-Meadow, 2016; Goldin-Meadow & Alibali, 2013; Iverson, 2010; Tversky, 2011), and this has been demonstrated empirically (e.g., Agostinho et al., 2015; Cook, Mitchell, & Goldin-Meadow, 2008; Esteve-Gibert et al., 2017; Holler, Turner, & Varcianna, 2013; Hu et al., 2014; Kelly, Özyürek, & Maris, 2009; Macken & Ginns, 2014). Despite its pivotal role in knowledge acquisition, the manipulation of speakers' gestures accompanying spatial information has been largely ignored by the literature as a potential avenue for examination. The work conducted in Chapter 3 demonstrates that empirically, the manipulation of the learning environment, through the production of speakers' gestures, is beneficial. For preschoolers, both verbal recall and physical route navigation were enhanced by the presence of gesture during encoding of spoken message.

The effect of gesture accompanying spatial information on listeners' verbal recall. Chapter 3 presented evidence that speakers' gestures accompanying spatial information benefit listeners' encoding and subsequent verbal recall of the spoken message. Children presented with a combination of iconic and deictic gestures accompanying route directions verbally reported more information than children presented with beat gestures or no gestures accompanying the spoken route directions. This finding suggests that as listeners, children benefit from the presence of speakers' gestures at encoding for spatial narratives. This finding also parallels existing research, which has shown that gestures (combination of iconic, metaphoric, deictic, and beat gestures, or only beat gestures) accompanying small-scale spatial information enhanced verbal recall of the spoken message for preschool aged children (Austin & Sweller, 2014). The work presented in Chapter 3 provides further evidence that gesture presents children with a valuable resource for information about spoken messages during early childhood when language skills are still developing (Sauter et al., 2012).

The effect of gesture accompanying spatial information on listeners' physical route navigation. Chapter 3 examined the effect of gesture within the context of physical route navigation. Preschoolers presented with a combination of iconic and deictic gestures or beat gestures, physically navigated more of the target route through the spatial array than preschoolers presented with only a verbal description of the route. This finding suggests that meaningful gestures (i.e., iconic and deictic) enhance recall with or without the presence of environmental cues, but that the benefit of beat gestures may only be apparent when recall is cued by the environment. To date, research has not examined the effect of observing gesture accompanying spatial route communication on listeners' physical route navigation. This thesis, therefore, presents the first evidence that gestures play a pivotal role in facilitating spatial knowledge acquisition and task performance during early childhood.

As discussed in Chapter 3, gestures are important for language learning, communication and cognition. Existing literature and the work presented in Chapter 3 together demonstrate that speakers' gesture production can be beneficial for listeners when gestures accompany spatial messages such as route direction information. Together with existing literature, Chapter 3 cements the importance of gestures in the context of spatial communication and cognition during early childhood. It was deemed important, therefore to clarify the role of gesture in cognition and communication once language and cognition had more fully developed, i.e., during adulthood.

Adults' Use of Gesture Accompanying Spatial Information

Following on from the effect of presenting gestures accompanying route direction information for young listeners in Chapter 3, across two experiments Chapter 4 examined whether gestures accompanying route directions through a large-scale environment benefited adult listener recall. In Experiment 1, the gestures accompanying route directions either primarily expressed the same meaningful information as the speech they accompanied (i.e., they were redundant), or had no apparent meaningful connection with speech (i.e., beat gestures). As argued in Chapter 4, redundant gestures are beneficial in instances when the spoken message is disrupted or unclear. Experiment 2 addressed whether non-redundant gestures accompanying route directions through a large-scale space benefited listener recall. Therefore, the gestures accompanying route directions in Experiment 2 were manipulated such that some expressed the same information as the speech they accompanied (i.e., they were redundant), and some conveyed information beyond the speech content (i.e., they were non-redundant). To achieve this we removed information from speech content. For a gesture in which the narrator was pointing left, for example, for the phrase "turn" replaced "turn left", both accompanied by a gesture pointing to the left. In the revised version only the gesture conveys the directional information, while in the original the directional information is conveyed through both speech and gesture. Furthermore, in order to investigate the role that cognitive ability plays in moderating the potential benefit of gesture for adults, and given the lack of research in the area, Chapter 4 examined the influence of an adult's spatial ability, vocabulary, and memory on information conveyed through both speech and gesture.

The effect of gesture accompanying spatial information on listeners' verbal recall. In Experiment 1 in Chapter 4, neither meaningful (iconic and deictic) gestures nor non-meaningful (beat) gestures enhanced participants' verbal route recall, relative to no gesture. In Experiment 2 however, when directional information was presented through gesture, listeners verbally recalled just as much route information when directional information was conveyed in both speech and gesture (i.e., the gestures were redundant) as when that information was missing from speech content and only presented through gesture (i.e., the gestures were non-redundant). This finding suggests that the additional processing of information conveyed through gesture enhances recall when information is missing from speech content.

Moreover, adults' self-reported spatial ability had an effect on spatial verbal recall, such that adults with higher spatial ability verbally recalled more than those with lower levels of spatial ability. In particular, listeners' spatial ability had a greater effect on the verbal recall of location and movement information than description information. This pattern was replicated when measures of adults' vocabulary and memory were included in the analysis. Taken together, these findings suggest that an adult's cognitive ability influences the relationship between encoding and recalling elements of spatial information (i.e., locations and movements) with higher cognitive abilities facilitating the processing and recall of spatial location and movement information. The findings presented in Chapter 4 parallel and extend existing research, which showed that redundant gestures (combination of iconic, metaphoric, deictic, and beat gestures, or only beat gestures) accompanying small-scale spatial information did not enhance adults' verbal recall of the spoken message (Austin & Sweller, 2014). The work presented in Chapter 4 provides evidence that gesture presents adults with a valuable resource for information about spoken messages when speech is incomplete.

The effect of gesture accompanying spatial information on listeners' physical route navigation. Physical route navigation is the practical application of listeners' encoded information of the spoken message during task performance onto the perceptual experience of the environment (Vanetti & Allen, 1988; Wochinger & Boehm-Davis, 1995). Chapter 4 revealed a different pattern of results for listeners' physical route navigation compared with verbal recall. As previously mentioned, the findings suggest that gesture enhances listeners' verbal recall when information is missing from speech content. In contrast, Experiment 1 found neither meaningful (iconic and deictic) gestures nor non-meaningful (beat) gestures enhanced participants' physical route navigation, relative to no gesture, while Experiment 2 found both redundant and non-redundant gestures had a detrimental impact on physical route navigation. For example, participants presented with gestures (redundant and non-redundant) accompanying route directions made critical deviations from the target path sooner and more frequently than individuals presented with no gesture.

One possible reason for the different pattern of findings between verbal recall and physical route navigation is in how the information was recalled. During verbal recall, adults were asked to recall route direction information in the same environmental conditions under which the information was encoded. It is possible that the similarity in encoding and recall environments may have supported the cognitive work required to create and maintain an imagined mental representation, thus leading to greater recall of route direction information. However, adults' processing of information conveyed through speech and gesture may not have led to an *accurate* imagined mental representation of the route. As such, route direction information conveyed through speech and gesture may have led to a discrepancy between listeners' imagined mental representation of the environment and the actual physical experience when navigating the route. Resolving the discrepancy between an imagined mental representation and the physical environment may require greater cognitive work, thus leading to less successful route navigation. Listeners with higher cognitive ability (verbal, spatial, memory) physically navigated more of the route when gestures (redundant and non-redundant) accompanied route directions than when no gestures accompanied route directions. Listeners with lower cognitive ability were less successful in physically navigating the route when gestures accompanied route directions than when no gestures accompanied route directions. This finding suggests that having higher cognitive abilities may then help listeners by resolving the discrepancy between the imagined and actual route environment, thereby leading to more successful route navigation.

The work presented in Chapter 4 is unique in its finding that speakers' gestures may *interfere* with adults' ability to recall route information during physical route navigation. To date, research has previously found benefits for gesture or no differences with only one study reporting an interference effect of gesture (Sekine & Kita, 2015). Here, however, potential costs to listeners' task performance are revealed when spatial information is accompanied by gesture. From a theoretical standpoint, the impact on listeners' task performance provides evidence that adults integrate speakers' speech and gesture at encoding during spatial communication. From a practical standpoint, Chapter 4 presents evidence that receiving route directions accompanied by gesture when lost in an unfamiliar city may lead to individuals getting lost while following those route directions. Importantly, the findings from Chapter 4 imply that the beneficial effect of gesture accompanying spatial content may depend on how the information is to be recalled. As argued throughout this thesis, the use of gesture accompanying spatial information plays a functional role in communication, both for speakers and listeners.

The Function of Gesture in Spatial Communication

As was established in Chapter 1, there has been limited examination among gesture researchers as to the developmental differences in the amount and type of spontaneous gesture produced and the effect of gesture accompanying spatial information on listeners' task performance. Based on embodied cognition and the Gesture as Simulated Action (GSA) framework for gesture production discussed in Chapter 1, it was argued that our physical interactions with the world ground our cognitive processes in the environment (Wilson, 2002). When performing tasks, both concrete and mental, we use the body (i.e., gestures) to offload information or cognitive work onto the environment, thereby assisting in the mental representation / manipulation of objects and / or ideas (Wilson, 2002). In other words, gestures embody our thought processes in the environment.

The GSA framework offers an account for how gestures make embodiment visible (Hostetter & Alibali, 2008). According to GSA, mentally simulating an action activates premotor action states and through spreading activation of motor areas, results in an overt gesture being produced (Hostetter & Alibali, 2008). Although GSA helps explain how some gestures come to be produced, it does not necessarily help us understand what gestures *do* for speakers who produce them or for their listeners (Novack & Goldin-Meadow, 2016). It has been argued throughout this thesis that the externalisation of thoughts through the production of gesture plays a functional role in thinking and communication both for the speakers who produce them and for their listeners (Wesp et al., 2001; Wilson, 2002).

The Function of Gesture in Communication for Speakers.

As previously mentioned, our ability to process, store and convey information depends on our cognitive characteristics (Just & Carpenter, 1992). Embodying thought processes through gesture production is thought to increase the cognitive resources available to concurrent thought processes (e.g., memory) by reducing the workload of the speech production system (Goldin-Meadow et al., 2001; Just & Carpenter, 1992; Wilson, 2002). Gestures re-represent action in the form of abstracted action. Consequently, offloading cognitive work into the environment through abstracted actions can extend the limitations of our cognitive characteristics, and thereby facilitate the thinking process (Macken & Ginns, 2014; Wilson, 2002). As with other tasks, gesture may serve two functions for speakers performing spatial tasks: 1) help speakers translate spatial knowledge / information into speech and / or 2) directly communicate spatial location / movement information, thereby eliminating the need to translate this information into speech (Hostetter & Alibali, 2008; Wilson, 2002).

Producing gesture helps speakers translate spatial knowledge into speech. Producing gestures during spatial task performance grounds thought processes in the environment, allowing speakers to offload cognitive work, thereby helping speakers translate spatial knowledge / information into speech (Tversky, 2011; Wilson, 2002). For speakers, producing gestures reduces the overall load on cognitive resources by reducing the workload of the speech production system, making more resources available for concurrent cognitive processes such as memory (Cameron & Xu, 2011). For example, communicating route direction information by pointing to the right accompanying the phrase “go right at the office”, reduces the resources needed by the speech production processes. Reducing the resources needed by speech production processes makes more resources available for recalling the route / maintaining the mental representation of the route in memory, thereby facilitating spatial knowledge communication.

The results of Chapter 2 supported the argument that gestures ground thought processes and communication in the environment, and in so doing, allow speakers to offload cognitive workload, facilitating the translation of spatial knowledge / information into speech. For both children and adults, producing pointing gestures accompanying route direction information reduces the resources needed by the speech production process. By conveying route elements (e.g., position, movement, direction), gestures make more resources available for creating and maintaining the mental representation of the route, thereby facilitating route direction communication (Cameron & Xu, 2011; Goldin-Meadow et al., 2001; Just & Carpenter, 1992; Wilson, 2002). As children's cognitive capacity is more limited than that of adults, producing enacting gestures reduces the resources needed by the speech production process, by directly conveying concrete route elements (e.g., shape, size, direction, movement) which may be beyond their current vocabulary (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007, 2008; Madan & Singhal, 2012; Wilson, 2002). This in turn makes more resources available for creating and maintaining the mental representation of the route, thereby facilitating route direction communication (Cameron & Xu, 2011; Goldin-Meadow et al., 2001; Just & Carpenter, 1992; Wilson, 2002).

At the same time, gestures provide speakers with feedback on their thought processes by reflecting mental representations (Goldin-Meadow & Alibali, 2013; Madan & Singhal, 2012; Wilson, 2002). The visual feedback of gesture (through form, position and movement) clarifies and emphasises aspects of the spoken message during the communication process, helping speakers to maintain and update mental representations of routes as the description progresses.

For example, conveying direction information through pointing gestures provides speakers with nonverbal clarification and emphasis of the direction or movement they simultaneously convey through speech. While gestures facilitate the management and allocation of mental resources, gestures may also enhance the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005).

Gesture production helps speakers communicate meaning through the construction of phrases. During spatial communication, gestures may also play a functional role in the construction of phrases and therefore, the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). For example, producing a gesture portraying automatic sliding doors to indicate a door, disambiguates it from a door which might be accompanied by a gesture portraying the turning of a door handle. In this way, producing gesture provides individuals with a means to communicate spatial knowledge and ideas (Goldin-Meadow & Alibali, 2013; Hostetter & Alibali, 2007; Madan & Singhal, 2012; Wilson, 2002).

The results of Chapter 2 supported the argument that gestures play a functional role in the construction of phrases and therefore, the communication of meaning (Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). The degree of additional information conveyed by gesture suggests that gestures help speakers transform knowledge and ideas into speech, particularly during early childhood. Importantly, the embodiment of thought processes through gesture production may have multiple functions for speakers which are not mutually exclusive.

This work brings together two areas of psychological research, gesture production and spatial cognition, to show how they work together when individuals engage with, and respond to, requests for novel spatial route information in social situations. Gestures embody an individual's thought processes and in so doing, provide speakers with a stable external physical and visual means through which to think and communicate (Pouw et al., 2014). In addition to these benefits for speakers, gestures are also beneficial for listeners. Listeners see gestures and encode and subsequently recall the spoken message, as demonstrated by this thesis (Chapters 3 and 4) as well as by prior research that has captured interactions between gesture and listener recall of words and sentences with non-spatial content (e.g., Cohen & Otterbein, 1992; Feyereisen, 2006; Thompson et al., 1998) as well as spatial content (Austin & Sweller, 2014).

The Function of Gesture in Spatial Communication for Listeners.

Although it is well established that recall for non-spatial spoken information may be enhanced by simultaneously viewing gestures, the influence of speakers' gestures on listener recall of spatial content is less well understood. In the context of spatial tasks, listeners must construct a mental representation of the route based on the speaker's speech and gesture (i.e., visualise space, understand spatial relations and orientation), without the benefit of previous perceptual and motor experience of the environment (Allen, 2000; Blades & Medlicott, 1992; Mark et al., 1999; Wochinger & Boehm-Davis, 1995). To form a mental representation of the speaker's spoken route directions and successfully move through both unfamiliar and everyday contexts, listeners must cognitively process and integrate a speaker's speech and gesture (Alibali & Hostetter, 2010; Cassell et al., 1999; Church et al., 2007; Tversky & Kessell, 2014). The construction of an imagined mental model of route directions places considerable demands on memory, particularly for unfamiliar environments (Allen, 2000). As with other tasks, gesture may serve two functions for listeners during spatial communication: 1) to help clarify the spoken message and / or 2) serve as an elaborate route direction encoding strategy, thereby facilitating spatial information recall (Just & Carpenter, 1992).

Gestures accompanying spatial information help to clarify the spoken message for listeners. Gestures accompanying spatial information ground spoken messages in the environment, facilitating listener encoding and subsequent recall of the spoken message. For listeners, gestures may scaffold speech comprehension by conveying route elements through pointing, depicting / enacting gestures, or through movement (Tversky & Kessell, 2014). In this way, speakers' gestures act to disambiguate or reinforce the spoken message and may be particularly beneficial when spoken route directions are complex, extensive or incomplete. By clarifying spoken language, gestures can help to create transient maps (mental representations) that preserve spatial route properties such shape and movement, thereby freeing cognitive resources for concurrent processes such as memory (Tversky & Kessell, 2014).

In line with this function, the work in this thesis (Chapters 3 and 4) has demonstrated that speakers' gestures accompanying spatial task information ground language comprehension in the environment and help clarify spoken language. It is possible that the concrete visual information conveyed through iconic and deictic gestures clarified and disambiguated elements of the spoken message which may be beyond the cognitive capacity of young children. This thesis has argued that gestures scaffold language comprehension by providing additional information and cues, thereby indirectly reducing the information processing demands of language comprehension and increasing cognitive resources for other processes such as memory.

The results of Chapter 4 also support the argument that gestures accompanying spatial task information ground language processing in the environment and help clarify spoken language during adulthood. The similarity in verbal recall when information was conveyed through redundant or non-redundant gestures presented in Chapter 4 suggests the processing of spatial information through multiple modalities. This in turn implies that gestures help clarify spoken language, and in so doing gestures can help to create transient mental representations, increasing the cognitive resources available for memory (Tversky & Kessell, 2014).

Gestures accompanying spatial information serve as an elaborate encoding strategy for listeners. During spatial communication, speakers' gestures may also serve as an elaborate route direction encoding strategy and therefore, reduce cognitive demands of speech comprehension. Embodied cognition suggests that for listeners, processing information conveyed in speech and gesture activates the same perceptual and motor states involved in gesture production, thus facilitating the generation of an imagined mental representation of the route (Alibali & Hostetter, 2010). This activation reduces the spatial information processing demands of memory by serving as an elaborate route direction encoding strategy (Alibali & Hostetter, 2010; Just & Carpenter, 1992; Madan & Singhal, 2012). In this way, listeners may create a richer and more elaborate imagined mental representation of route directions accompanied by gesture than of route directions conveyed through speech alone. Given that people have limited mental resources, a richer imagined mental representation reduces the information processing demands of speech comprehension, thereby increasing the resources available for the transient processing and storage demands of the task (e.g., route direction comprehension; Just & Carpenter, 1992). For listeners, gestures accompanying route direction information may reduce spatial information processing demands and result in greater resources available for task demands such as verbal recall and physical route navigation.

The results of the study in Chapter 3 supported the argument that during development, gestures serve as an elaborate encoding strategy, thereby increasing the resources available for task demands. The simulated mental images listeners formed when presented with route directions accompanied by beat gestures may not be strong enough to enhance recall without the presence of environmental cues. Despite containing no apparent semantic meaning in and of themselves, beat gestures may act to emphasise the route characteristics which they accompany, thereby enhancing recall when prompted by environmental cues (So et al., 2012). Conversely, iconic and deictic gestures may be processed more deeply due to their semantic value, leading to greater recall without the presence of environmental cues (Woodall & Folger, 1981). The findings from Chapter 3 suggest that gestures which simulate the real world (i.e., iconic and deictic) enhance recall with or without the presence of environmental cues, but that the benefit of beat gestures may only be apparent when recall is cued by the environment.

As has been discussed, previous research has shown that children's memory of a target path through a small-scale spatial array was found to be enhanced by the presence of gesture accompanying the spoken message (Austin & Sweller, 2014). Together with existing literature, the findings presented in Chapter 3 provide further evidence that gesture presents children with a means for encoding spatial information (elaborate encoding strategy) during early childhood when language skills are still developing, making more resources available for task demands (e.g., recall; Sauter et al., 2012).

Chapter 4 also demonstrated that gestures can serve as an elaborate route direction encoding strategy for adult listeners, and therefore reduce the cognitive demands of speech comprehension during adulthood. It is possible that gestures enhance adults' verbal recall when compensating for missing verbal information, but not when gesture replicates verbal information. In turn, this finding implies that messages accompanied by gestures are processed through multiple modalities (i.e., gestures serve as an elaborate route direction encoding strategy) and that the additional information processing of visual and motor information provided by gestures enhances recall when information is missing from speech content.

Chapter 4 also found, however, that adults' physical route navigation was more successful when gestures did not accompany route direction information. It is likely that poorer route navigation by individuals presented with route information accompanied by gesture suggests that deeper processing and more elaborate mental representations of route direction information elicited by messages conveyed through speech and gesture may have led to a mismatch between listeners' imagined mental representation of the environment and the actual physical experience when navigating the route. In other words, gestures enhanced verbal recall because of the similarity in encoding and recall conditions. When encountered with the actual route which did not match the imagined route, gestures were detrimental due to the mismatch that was created. This finding strengthens the argument that gestures accompanying spatial information facilitate listeners' creation of an imagined mental representation. Listeners' cognitive ability may influence the role of gesture in processing spatial information.

The function of gesture may depend on the listener's cognitive ability. Given gesture's role in reducing the cognitive demands of spatial information processing, an individual's cognitive ability (e.g., vocabulary, spatial ability, memory) may influence the role of gesture in clarifying and / or serving as an elaborate route direction encoding strategy, thereby facilitating spatial information recall. As previously mentioned, spatial ability is an important aspect of encoding and recalling spatial information (Chu & Kita, 2011; Hostetter & Alibali, 2007; Vanetti & Allen, 1988). The findings from Chapter 4 suggest that having higher spatial abilities may help listeners by resolving the discrepancy between the imagined and actual route environment, influencing the resources available for the transient storage demands of the task, thereby leading to more successful route navigation.

This thesis has argued that, because gesture grounds language in the physical world, there are multiple interdependent pathways whereby gesture might benefit listeners. Gestures scaffold language comprehension by providing additional information and cues, thereby indirectly reducing the information processing demands of language comprehension and increasing cognitive resources for other processes such as memory. Alternatively, processing speech and gesture creates a stronger mental representation of the spoken message, leaving a richer trace in memory, thereby increasing the resources available to other cognitive processes. Although these two possibilities are not mutually exclusive, further research is needed to better understand the functional role gesture plays in communication for listeners.

Limitations and Future Directions

There are some acknowledged limitations and additional questions that have arisen as a result of the work conducted, some of which have already been discussed. This section will detail three further limitations and potential areas for future research: 1) examination of the complex relationship between the information preschoolers convey through speech and gesture; 2) exploration of developmental differences in listeners' use of redundant and non-redundant gesture; and 3) clarification of older adults' use of redundant and non-redundant gesture.

The complex relationship between speakers' speech and gesture. While the relationship between speech and gesture was investigated in multiple ways, there are still more avenues to explore. Gesture production is related to speech (as was demonstrated in Chapter 2), and alters listeners' recall (Chapter 3 and 4), but it is still unknown whether the morphological features of gestures produced during early childhood correspond to the visual aspects of spoken referents, and whether a close match between morphological features of a gesture is related to recall accuracy. Research by Cassell et al. (2007) found evidence that the form of a gesture relates to characteristics of the entity to which it refers (that is, the shape of the hand performing the gesture relates to a characteristic of the object or movement being conveyed at the time the gesture is performed). The concept of gestures reflecting thought processes, which is a fundamental aspect of gesture production theory (as discussed in Chapter 1), posits that gesture re-represents perceptual and motor knowledge (see Tversky, 2011; Hostetter & Alibali, 2008, for a discussion of gesture reflecting thought processes). Given the exploratory nature of the study in Chapter 2 and the complexity of the relationship between speech and gesture, developmental differences in the relationship between the morphological characteristics of gesture, the spoken referent and route accuracy were not examined. This could be addressed by a closer examination of differences between children and adults in the relationship between the form, position and movement of gesture and speech content, for example, as performed by Cassell et al. (2007) in conjunction with measurement of route recall accuracy. An additional, related question that was raised by the work in the thesis, particularly Chapters 3 and 4, is whether the information conveyed through gestures produced by a speaker is important for listener recall.

Developmental differences in listeners' use of different types of gesture. The methodology utilised in the study in Chapter 3, which presented participants with speech and depending on assigned condition, accompanying gestures, was appropriate for identifying the effect of gesture at encoding on recall. However, the gestures presented in the task were redundant. As a result, the gestures presented young children with a single message via verbal and visual means. While this allowed a comparison of the types of gestures (iconic and deictic, beat) between groups, it did not allow a comparison between redundant and non-redundant gestures. The comparison of types of gesture brought about an expected finding, namely the enhanced recall of spatial information for preschoolers presented with gesture, which sets the foundation for another avenue for future research. Future work should investigate the effect of presenting children at different stages of development with gestures that provide additional information (i.e., non-redundant gestures) to speech on spoken message recall compared to gestures which express the same information as speech (i.e., redundant gestures); and discover any differences in the additional information processing load of gesture (non-redundant) versus a consistent gesture (redundant). As was argued in Chapter 4, future research should also examine the implications of developmental differences in cognitive ability to see if gesture facilitates recall at different rates depending on cognitive abilities (e.g., language) during different stages of development.

Differences across the lifespan in listeners' use of different types of gesture. Finally, Chapters 3 and 4 demonstrated that gestures can have different effects at different times throughout the lifespan, which raises the possibility that gestures accompanying speech may be particularly important when cognitive abilities such as language, memory and information processing decline during older adulthood (Austin & Sweller, 2014; Postma, van Oers, Back, & Plukaard, 2012; Wochinger & Boehm-Davis, 1995). In the empirical study presented in Chapter 4, the targeted population being studied meant the sample was composed of undergraduates. While first and second-year psychology students were recruited in an attempt to achieve a broader age range than the usual sample of only first-year students, there was inevitably some age bias, and the final sample was comprised primarily of adults between the ages of 18 and 30. Existing research suggests that older adults are poorer at navigation than younger adults, with age-related differences seen in global configuration (i.e., locating landmarks) and in judgments of indirect spatial sentences (Gyselinck, Meneghetti, Bormetti, Orriols, Piolino, & DeBeni, 2013; Postma et al., 2012; Wochinger & Boehm-Davis 1995). Ideally, middle-aged and older-aged adults would have been included in the sample, in order to compare the effects of gesture at different ages across the lifespan, but this was beyond the scope of the current studies. It is important to examine whether gestures accompanying spatial information enable individuals at different points across the lifespan to overcome cognitive deficits (i.e., language, memory, and processing speed; Postma et al., 2012; Wochinger & Boehm-Davis 1995). In terms of development, establishing the link between gestures accompanying speech and task performance is important for developing an understanding of gesture as a source of information for listeners across the lifespan.

Conclusions

There were three major findings from the work presented in this thesis. First, that preschoolers' spatial knowledge is deeper than that which their limited vocabulary allows them to verbally express. By using gestures to represent visual characteristics and directions, preschoolers can convey the physical qualities of the route and the movements required beyond the limitations of their developing vocabulary. By examining differences between adults' and preschoolers' use of gesture in relation with speech it was possible to capture some developmental changes in spatial cognition and language, beyond that which speech alone allows. These differences highlight the need to include measures of gesture when examining cognition and language during development.

Second, young children benefited from the presence of gesture accompanying spatial route direction information. While iconic and deictic gestures provided benefits for both verbal and cued (physical navigation) recall, beat gestures were more limited in their effects, enhancing performance above that of no gestures for cued recall only. By examining the effect of different types of gesture on preschoolers’ recall this thesis captured some of the role gesture plays during communication for listeners during language and cognitive development.

Third, for adult listeners, gestures were most important when speakers’ spoken messages were missing information. The differences in adult route recall strongly support the view that information processed through verbal and non-verbal modalities benefits adult listeners by facilitating imagined mental representations, particularly when information is missing from the spoken message. Moreover, these differences provide a greater understanding of the role gesture plays during communication for adult listeners, indicating that gesture is an integral part of communication when spoken messages are incomplete. This thesis shows that much can be learned by considering the intricacies of how speech, gesture and cognition work together during spatial communication.

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Appendix A: Supplementary Material for Chapter 3.

Verbal Description of the Target Path

Note. Underlined words indicate gesture points.

(1) The koalas are in front of you

(2) Walk forwards for a little bit

(3) And go under the butterfly sign

(4) Go past the penguin pond

(5) Go around the bright red bird

(6) The trees are really tall along here

(7) Go past the frogs

(8) Keep going ahead

(9) Go through the elephant enclosure

List of Locations, Movements, and Descriptions

Location terms to be recalled:

(1) Koalas

(2) Butterfly sign

(3) Penguin pond

(4) Bird

(5) Trees

(6) Frogs

(7) Elephant enclosure

Movement terms to be recalled:

(1) Forwards

(2) Go under

(3) Go past

(4) Go around

(5) Go past

(6) Go ahead

(7) Go through

Description terms to be recalled:

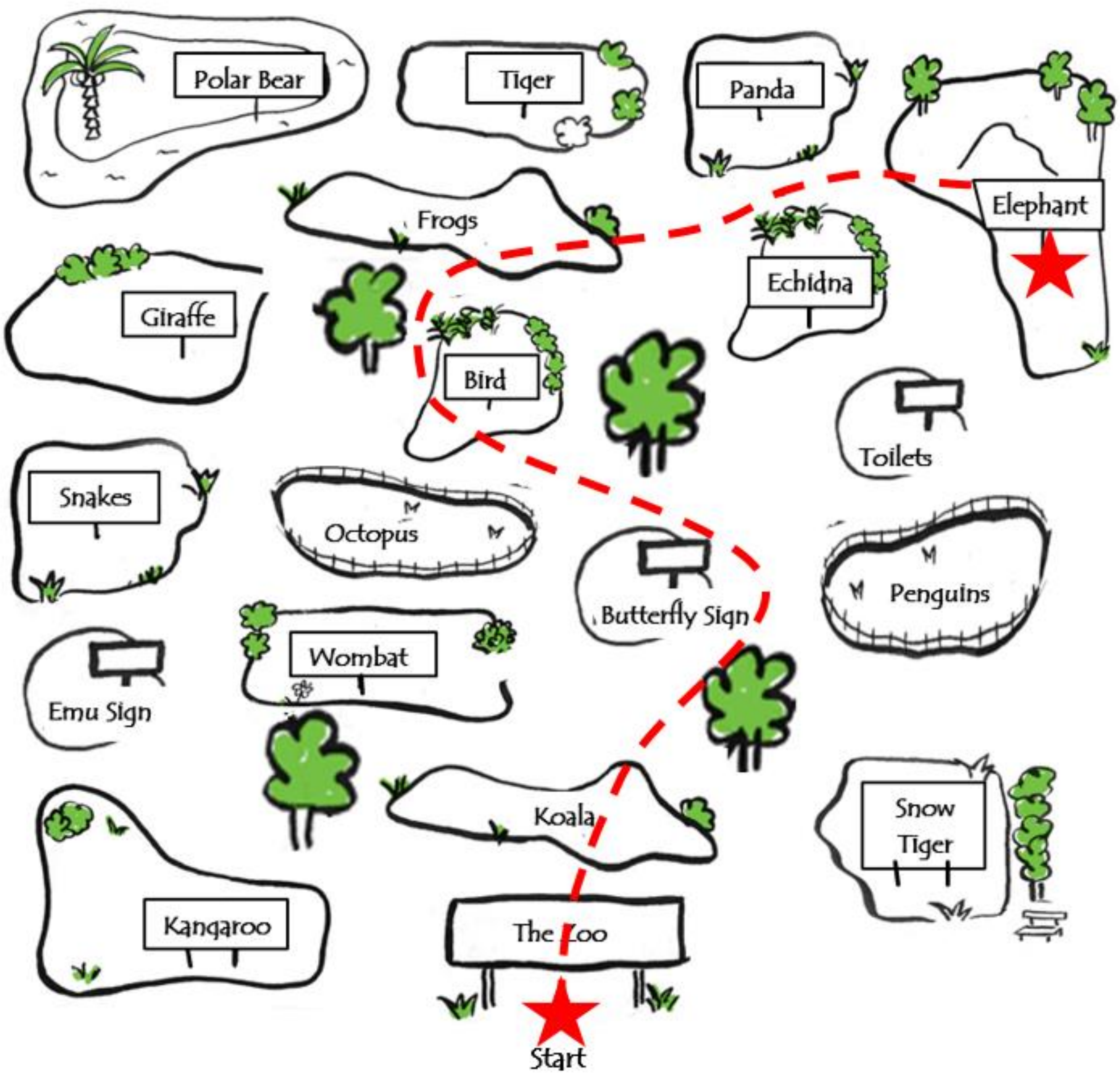
(1) A little bit

(2) Bright red

(3) Really tall

Layout of the Zoo Stimuli and Target Path

Note. Red line indicates the target path. Stars indicate the beginning (start) and end (at the elephants) of the target path.



Photographs of objects within the spatial array

Note. Picture do not reflect relative size of object.

Appendix B: Supplementary Material for Chapter 4.

Redundant Verbal Description of the Target Path

Note. Underlined words indicate gesture points. Accompanying gestures for the iconic-deictic gesture condition are in italics.

(1) so first you go out the door *iconic: pantomime opening a door outwards*

(2) And turn left *deictic: chop action left*

(3) And at the corner turn right *deictic: point right*

(4) Go to the end of the hallway *deictic: chop action forwards*

(5) and through the small waiting room with kids toys *deictic: pointing down as the hand moves forwards*

(6) Keep going straight *deictic: chop action forwards*

(7) Going down the hallway *deictic: chop action forwards*

(8) And go past the elevators *deictic: chop action forwards*

(9) Walk to the bottom of the wooden stairs *deictic: pointing down*

(10) Turn to the right *deictic: chop action right*

(11) And go towards the café *deictic: chop action forwards*

(12) Keep walking straight for a little bit *deictic: chop action forwards*

(13) And at the door go outside *deictic: chop action forwards*

(14) And go down the stairs *deictic: points down*

(15) There is a large flat grass area in front of you *iconic: open hands palms down moves forward and out*

(16) Walk left following the outside of the glass building *iconic: pantomime large rectangular object/ building – hands move up*

(17) Keep going left *deictic: chop action left*

(18) The road will be on the right *iconic: pantomime road (long narrow flat) on the right*

(19) Go left at the corner of the building *deictic: chop action left*

(20) Walk in through the double glass doors *deictic: chop action forwards*

(21) Go straight ahead *deictic: chop action forwards*

(22) The lounges will be on the left *deictic: points left*

(23) In the elevator go to level 3 *deictic: points up*

(24) There are stairs on the right *deictic: points right*

(25) And on the left is a patio area *iconic: pantomime rectangular space to the left*

(26) Go down the stairs *deictic: points down*

(27) Turn right *deictic: chop action right*

(28) Walk past the small white coloured kitchen area *deictic: points down moves forward*

(29) The elevators are on the left *deictic: points left*

(30) Take the elevator to level 1 *deictic: points down*

(31) There is a small sitting area in front of the elevators on level 1 *deictic: point forwards*

(32) The toilets are on the left *deictic: points left*

(33) Go down the hallway opposite the stairs *deictic: points forwards*

(34) Keep going straight *deictic: chop action forwards*

(35) Go through the door *iconic: pantomime opening a door outwards*

(36) And there is a window on the left wall *deictic: points left*

(37) Turn right *deictic: points right*

(38) Go through that door *deictic: chop action forwards*

(39) Walk straight ahead for a little bit *iconic: pantomime corridor*

(40) Turn left at the end of the hall *deictic: points left*

(41) And turn right into the room *deictic: points right*

Non-redundant Verbal Description of the Target Path

Note. Underlined words indicate gesture points. Accompanying gestures for the iconic-deictic gesture condition are in italics.

(1) so first you go out the room *iconic: pantomime opening a door outwards*

(2) And then you turn *deictic: chop action left*

(3) And at the corner turn again *deictic: point right*

(4) Go to the end of the hallway *deictic: chop action forwards*

(5) and through the small waiting room with kids toys *deictic: pointing down as the hand moves forwards*

(6) Keep going *deictic: chop action forwards*

(7) Going down the hallway *deictic: chop action forwards*

(8) And go past the elevators *deictic: chop action forwards*

(9) And take the wooden stairs *deictic: pointing down*

(10) Turn *deictic: chop action right*

(11) And go towards the café *deictic: chop action forwards*

(12) Keep walking for a little bit *deictic: chop action forwards*

(13) And at the door go outside *deictic: chop action forwards*

(14) And take the stairs *deictic: points down*

(15) There is a large grass area in front of you *iconic: open hands palms down moves forward and out*

(16) Walk left following the outside of the glass building *iconic: pantomime large rectangular object/ building – hands move up*

(17) Keep going *deictic: chop action left*

(18) The road will be next to you *iconic: pantomime road (long narrow flat) on the right*

(19) Turn at the corner of the building *deictic: chop action left*

(20) Walk in through the double glass doors *deictic: chop action forwards*

(21) Keep going *deictic: chop action forwards*

(22) The lounges will be on one side *deictic: points left*

(23) In the elevator go to level 3 *deictic: points up*

(24) There are stairs on one side *deictic: points right*

(25) And on the other is a patio area *iconic: pantomime rectangular space to the left*

(26) Take the stairs *deictic: points down*

(27) Turn here *deictic: chop action right*

(28) Walk past the small white coloured kitchen area *deictic: points down moves forward*

(29) The elevators are on over there *deictic: points left*

(30) Take the elevator to level 1 *deictic: points down*

(31) There is a small sitting area in front of the elevators on level 1 *deictic: point forwards*

(32) The toilets are on to the side *deictic: points left*

(33) Go down the hallway opposite the stairs *deictic: points forwards*

(34) Keep going *deictic: chop action forwards*

(35) Go through the door *iconic: pantomime opening a door outwards*

(36) And there is a window on the wall *deictic: points left*

(37) Turn *deictic: points right*

(38) Go through that door *deictic: chop action forwards*

(39) Keep walking for a little bit *iconic: pantomime corridor*

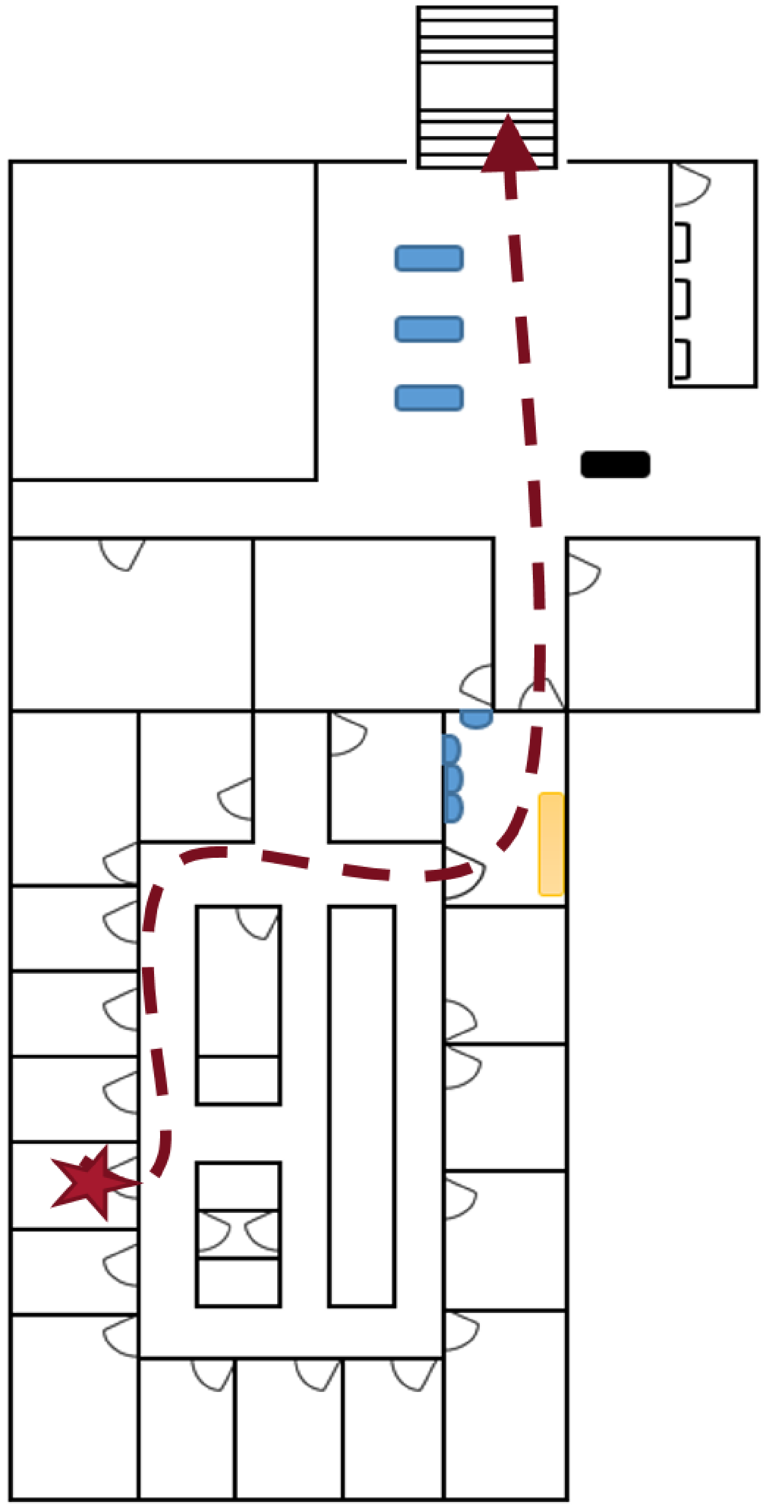
(40) Turn at the end of the hall *deictic: points left*

(41) And turn into the room *deictic: points right*

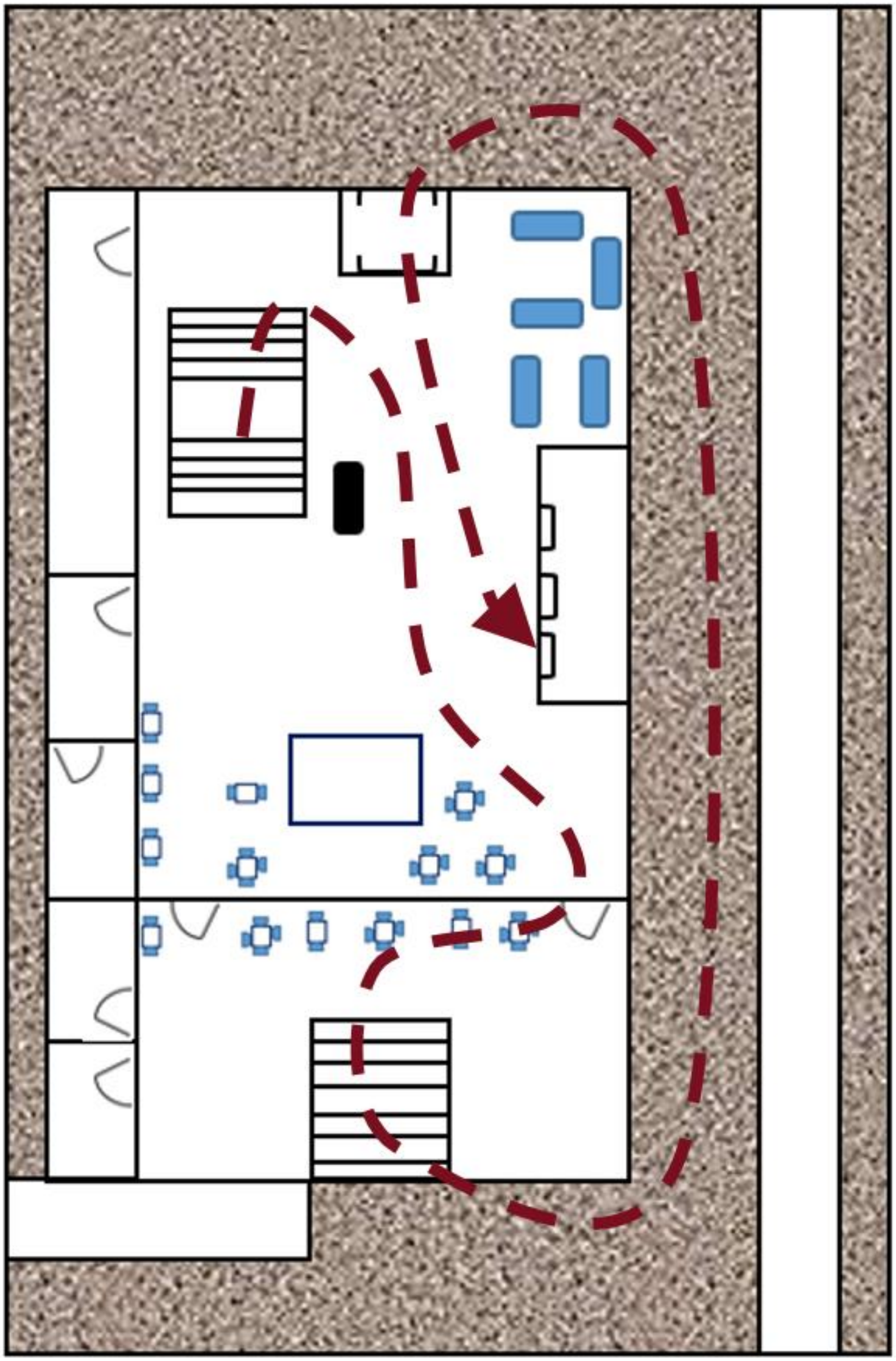
Layout of the University Building and Target Path

Note. Red line indicates the target path. Stars indicate the beginning and end of the target path.

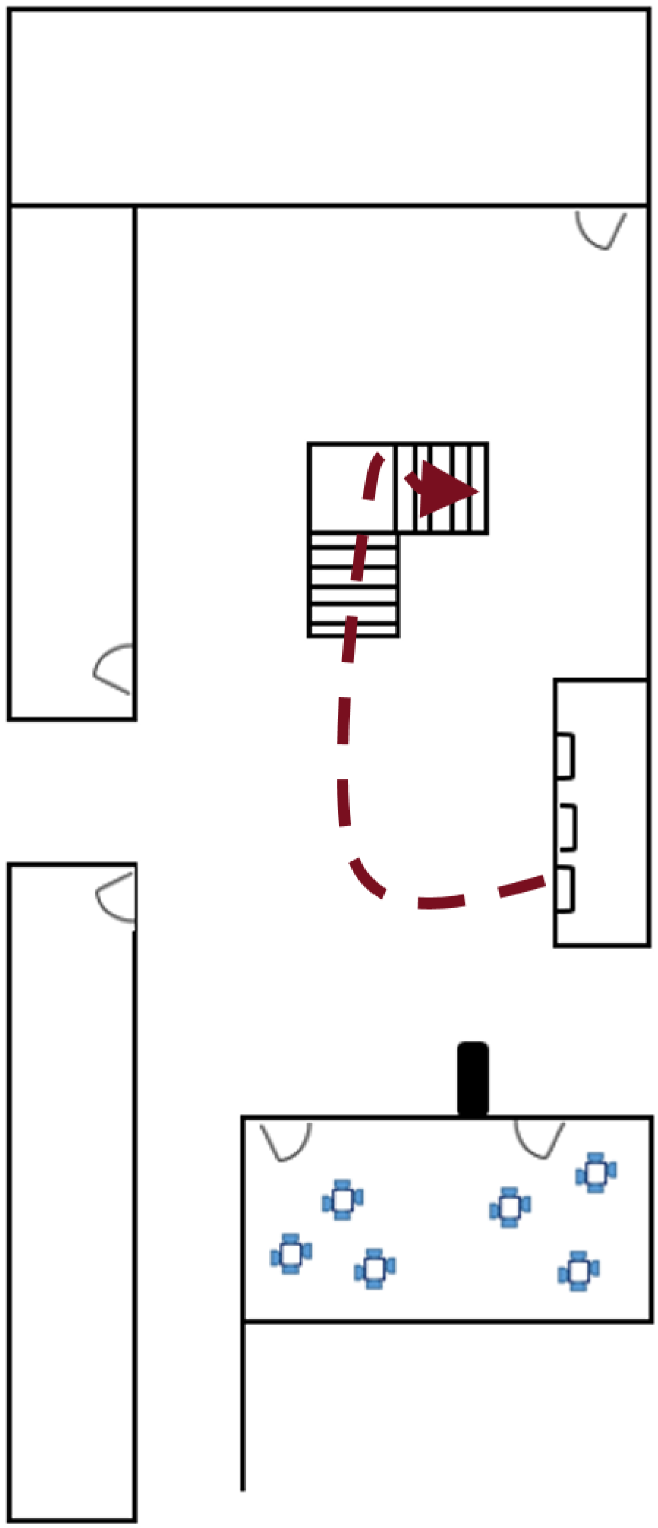
Level 1.



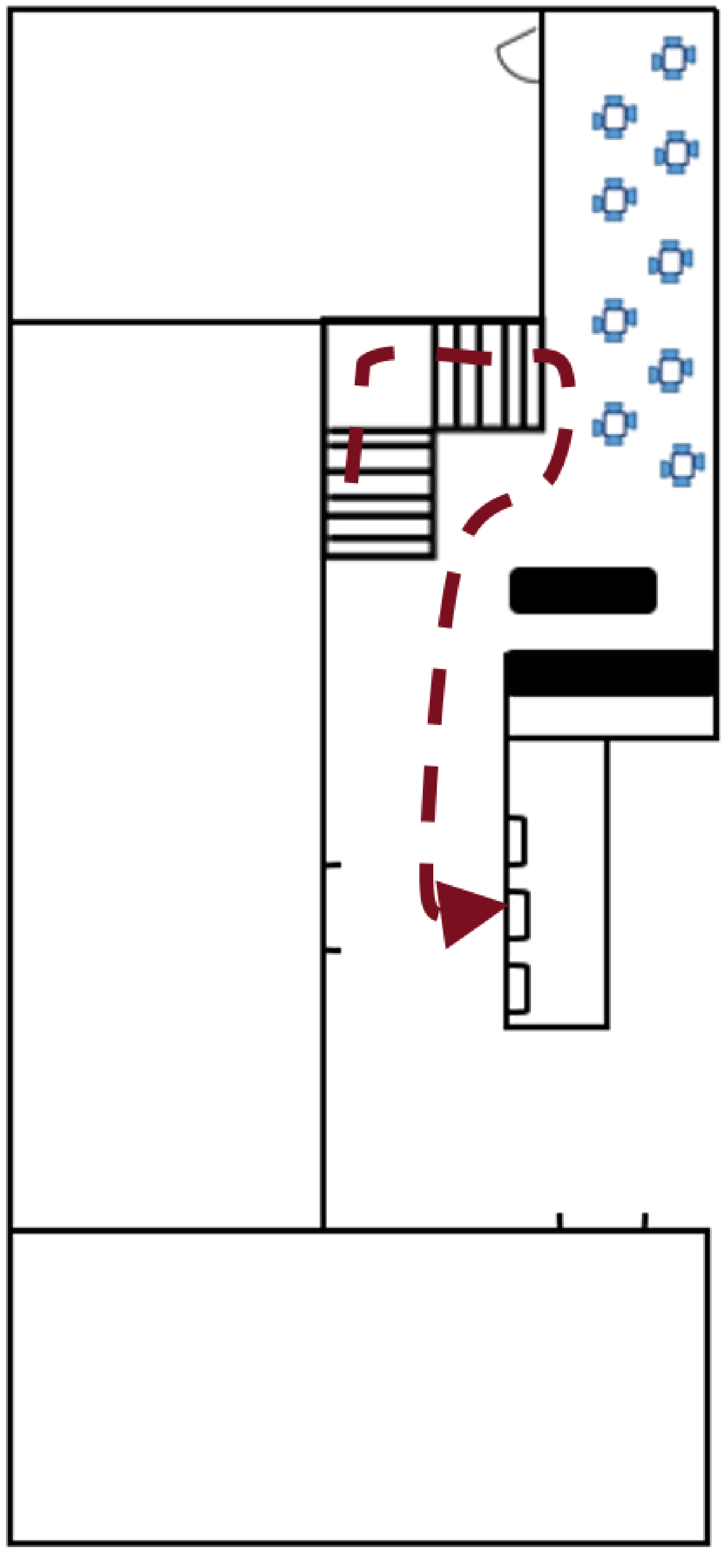
Ground Floor.



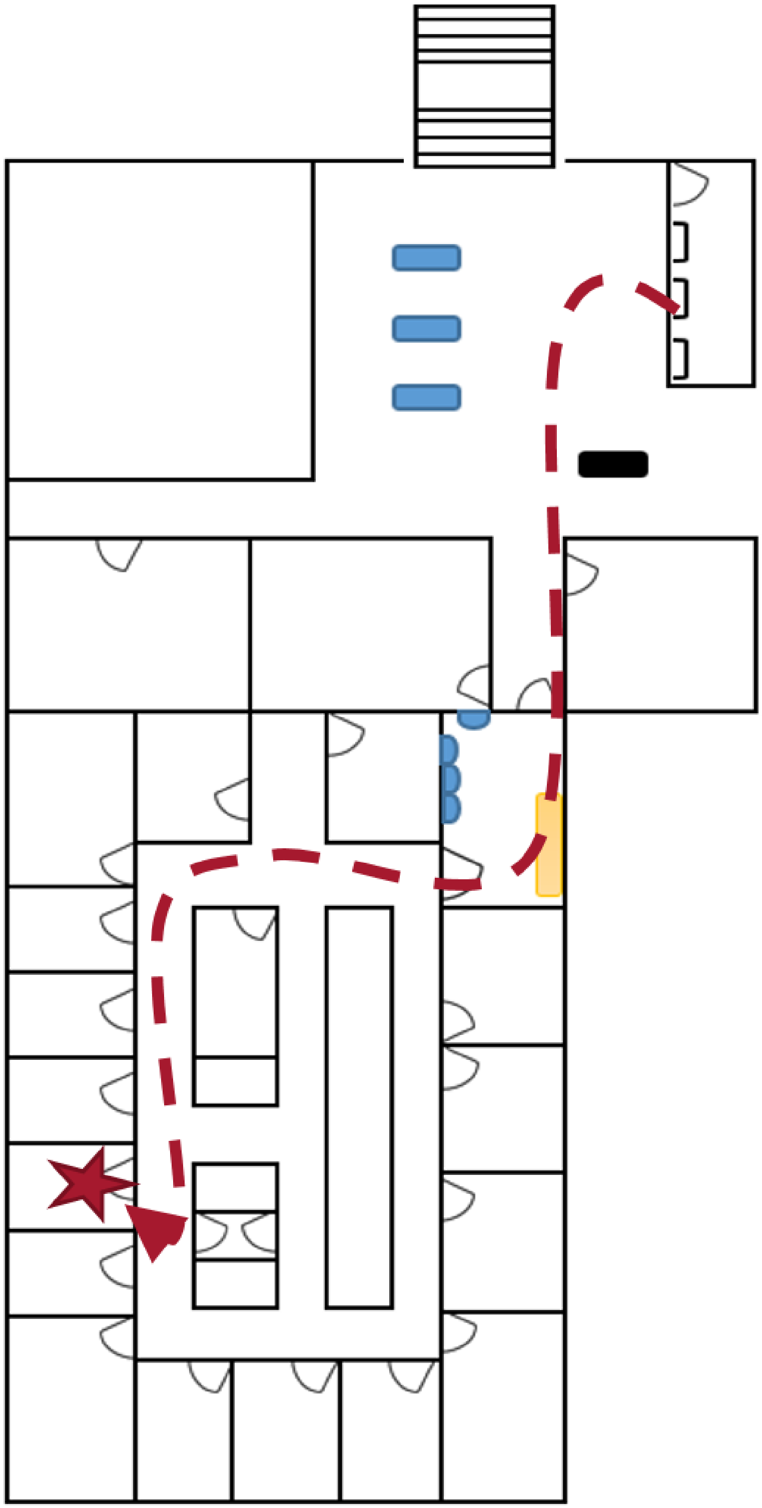
Level 3.



Level 2.



Level 1.



Appendix C: Letter of Approval from the Macquarie University Human Research Ethics Committee for Chapters 2 – 4

MACQUARIE University

ELIZABETH AUSTIN <elizabeth.austin@students.mq.edu.au>

RE: HS Ethics Application - Approved (5201300337)(Subject to Condition/s)

Fhs Ethics <fhs.ethics@mq.edu.au> Tue, May 21, 2013 at 12:36 PM
To: Dr Naomi Sweller <naomi.sweller@mq.edu.au>
Cc: Miss Elizabeth Erin Austin <elizabeth.austin@students.mq.edu.au>

Dear Dr Sweller,

Re: "Perception and Production: The Role of Gesture in Spatial Communication"(5201300337)

Thank you for your recent correspondence. Your response has addressed the issues raised by the Faculty of Human Sciences Human Research Ethics Sub-Committee, effective 21st May 2013. This email constitutes ethical approval only.

This approval is subject to the following condition/s:

1. Please forward the approval from each centre for our records when this information becomes available.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:

Dr Naomi Sweller
Miss Elizabeth Erin Austin

NB. STUDENTS: IT IS YOUR RESPONSIBILITY TO KEEP A COPY OF THIS APPROVAL EMAIL TO SUBMIT WITH YOUR THESIS.

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 21st May 2014
Progress Report 2 Due: 21st May 2015
Progress Report 3 Due: 21st May 2016
Progress Report 4 Due: 21st May 2017
Final Report Due: 21st May 2018

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:
http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in

an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

5. Please notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

http://www.mq.edu.au/policy/
http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the FHS Ethics at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely,

Dr Peter Roger
Chair
Faculty of Human Sciences
Human Research Ethics Sub-Committee

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Appendix D: Letter of Approval from the Macquarie University Human Research Ethics Committee for Chapter 4

MACQUARIE University

ELIZABETH AUSTIN <elizabeth.austin@students.mq.edu.au>

RE: HS Ethics Application - Approved (5201500835)(Con/Met)

Fhs Ethics <fhs.ethics@mq.edu.au> Fri, Nov 6, 2015 at 12:20 PM
To: Dr Naomi Sweller <naomi.sweller@mq.edu.au>
Cc: Miss Elizabeth Erin Austin <elizabeth.austin@students.mq.edu.au>

Dear Dr Sweller,

Re: "Spatial communication: The benefits of non-redundant gesture at encoding on listener route direction recall"(5201500835)

Thank you very much for your response. Your response has addressed the issues raised by the Faculty of Human Sciences Human Research Ethics Sub-Committee and approval has been granted, effective 6th November 2015. This email constitutes ethical approval only.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:

Dr Naomi Sweller
Miss Elizabeth Erin Austin

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 6th November 2016
Progress Report 2 Due: 6th November 2017
Progress Report 3 Due: 6th November 2018
Progress Report 4 Due: 6th November 2019
Final Report Due: 6th November 2020

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/current_research_staff/human_research_ethics/application_resources

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Sub-Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Sub-Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/current_research_staff/human_research_ethics/managing_approved_research_projects

5. Please notify the Sub-Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

http://www.mq.edu.au/policy

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely,

Dr Anthony Miller
Chair
Faculty of Human Sciences
Human Research Ethics Sub-Committee

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