Infant verb understanding and its links with motoric experiences

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Summary of the Thesis

Developmental theories of word learning seek to chart early linguistic milestones and aim to explain how children acquire words. Verbs are an important aspect of word learning, enabling children to communicate about actions, events, and dynamic elements of the world around them. As a primary aim, this thesis investigates whether infants have begun grasping the meaning of their first verbs by the age of 10 months. In Chapter 1, I describe how children struggle to learn verbs compared to nouns and review theories explaining this difficulty. I discuss this in reference to the "verb learning paradox" and stress the importance of investigating infants' verb comprehension. I outline several mechanisms that may explain how children to learn verbs, including children's own bodily actions. As such, as a secondary aim of this thesis, I explore links between infants' motoric experiences and their verb comprehension.

In Chapter 2, I present two studies exploring verb comprehension with infants aged 10- and 14-months-old using looking while listening paradigms. I show that 14-month-olds understood several verbs in the task but 10-month-olds largely performed at chance, only recognising a small number of items. I discussed several potential reasons why 10-month-olds may have struggled to understand verbs during this task. In Chapter 3, I build upon this work by investigating 10-month-olds' verb comprehension using an implicit, neural measure of word understanding; the N400 event-related potential. I found evidence that 10-month-olds understood verbs during a semantic-priming task with a larger N400 response to mismatched, compared to matched, actions and verbs. Finally, in Chapter 4, I explored whether motor skills are differentially associated with concurrent verb, compared to noun, comprehension during the first two years of life. I show evidence that although both verb and noun understanding are linked with children's concurrent motor skills, verb comprehension holds an especially tight association with motor development.

To conclude, the findings from this thesis broaden the current understanding of the early lexicon, demonstrating that infants grasp the meanings of several verbs by at least 10 months. In Chapter 5, I discuss how future research should aim to explore which mechanistic processes support infants' verb learning at this early stage of development. Further, my findings show that infants' motor skills are strongly linked with their verb understanding, highlighting the importance of future research to explore the potential role infants' actions may play in their verb learning.

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Chapter 1. General Introduction

Words are the foundation of language. In developmental science, theories of lexical acquisition seek to understand how children acquire words and aim to chart the time course of important linguistic milestones. Verbs are an important aspect of every lexicon, allowing language users to describe the dynamic aspects of life such as actions and events. In developmental literature, it has long been noted that children find verbs difficult to learn. Verbs appear much later and far less often in children's productive vocabularies than nouns (Gentner, 1982; Gentner & Boroditsky, 2001). Despite this difficulty, there are still *some* verbs present in children's earliest spoken vocabulary (Maguire et al., 2006). Combined, this evidence shows that children begin finding their way through the verb learning problem early in their language learning, but when do children first start grasping the meaning of verbs? The primary aim of this thesis is to begin answering this question by exploring the onset of verb understanding during infancy, using a combination of empirical word comprehension measures.

In this introductory chapter, I will provide an overview of evidence highlighting children's difficulty learning verbs compared to nouns and review literature exploring the reasons *why* verbs are hard for children to learn. This evidence will be discussed in light of the "verb learning paradox" (Maguire et al., 2006) and why shifting focus to verb comprehension may provide insight into to children's broader verb learning journeys. The proposed mechanisms by which children acquire words varies across theoretical accounts of lexical acquisition (e.g., innate biases, social pragmatic skills, associative learning, syntactic bootstrapping), which I outline in respect to verb learning. Nonetheless, theorists of language development broadly agree that verb learning involves three key skills: (1) identifying a verb (finding a verb within continuous speech), (2) forming an action concept (attending and categorising actions), and (3) linking a verb with an action category (Gentner, 1982; Golinkoff et al., 2002). Thus, in this chapter, I summarise studies demonstrating that these skills are often present during infancy and, thus, warrant exploration of verb comprehension during the first year of life. I also discuss how recent studies of motor development suggest infants' own actions may support their language learning with the view to also explore associations between infants' motoric development and their verb acquisition as a secondary aim of this thesis. Finally, I overview several measures of word understanding appropriate for assessing verb comprehension during infancy, all of which are applied across this thesis.

1.1. The Verb Learning Problem

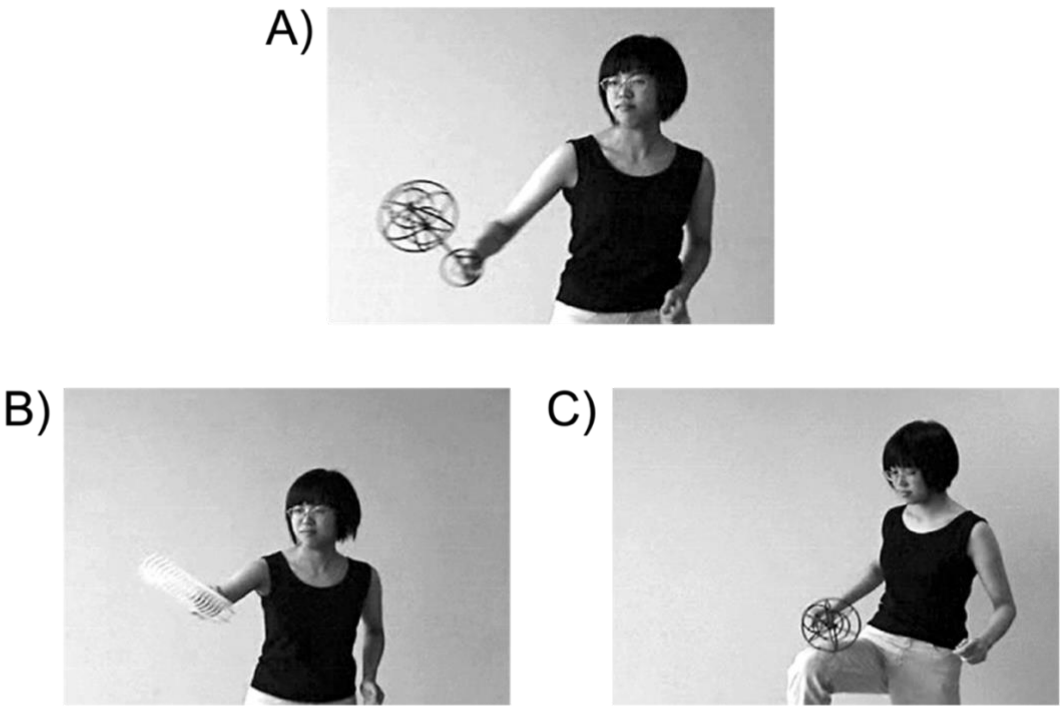
1.1.1. Children Find Verbs Hard to Learn

Around their first birthday, infants start to say their first words. For many infants, these words first describe caregivers and other important familiars that feature in their daily lives (e.g., "mummy", "dog"; Fenson et al., 1994; Tardif et al., 2008). From this time, infants continue to acquire their first 50 words slowly, learning to produce approximately two words a week (Carey, 1978). Between 18- and 24-months-old, infants' vocabulary rapidly begins to grow, with infants producing many more new words each week, a phenomenon known as the "vocabulary spurt" (Goldfield & Reznick, 1990). Interestingly, language inputs from caregivers utilise many different word types (e.g., nouns, verbs, pronouns) and, yet many of children's early spoken words do not proportionally represent the varied word types they are exposed to across their early development (Au et al., 1994). Indeed, reports of children's developing lexicons describe vocabularies dominated by nouns with few verbs present, which has been coined as the "noun bias" (Benedict, 1979; Fenson et al., 1994; Goldin-Meadow et al., 1976; Nelson, 1973). This literature shows that children find verbs more difficult to learn than nouns, appearing later in children's productive lexicons and far less frequently that noun items (Gentner, 1978, 1982; Gentner & Boroditsky, 2001). This pattern is seemingly universal, with similar findings being found across several languages. This was initially demonstrated in children speaking English, German, Kaluli, Japanese, Mandarin, and Turkish (Gentner, 1982) and later replicated in Spanish, Italian, French, Dutch, Hebrew, and Korean (Bornstein et al., 2004; Caselli et al., 1995; Jackson-Maldonado et al., 1993, but see Choi & Gopnik, 1995; Tardif, 1996; Tardif et al., 1999).

Children are also known to have difficulty acquiring novel verbs compared to object names in lab settings, failing to generalise novel verbs to new situations (Forbes & Farrar, 1995; Imai et al., 2005, 2006, 2008; Kersten & Smith, 2002; Schwartz & Leonard, 1984). This is evident cross-linguistically as demonstrated in several experiments conducted by Imai and colleagues (2008) in three different languages (English, Japanese, and Mandarin). Children aged 3- and 5-years-old were shown a video of a model completing a novel action on a novel object (see **Figure 1.1**) and were taught a new verb ("Look! She is *daxing* it!") or a new noun ("Look! This is a *dax*!"). At test, children were shown two new videos, side-by-side, displaying either the same object with a new action or the same action with a new object (see **Figure 1.1**). In the noun condition, children were asked "Where is the *dax*?" and in the verb condition "Where is she *daxing* it?". Both 3- and 5-year-old children readily extended novel nouns to other exemplars, but only 5-year-olds did so for novel verbs. Despite Japanese and Mandarin being considered “verb friendly” languages (i.e., verbs hold privileged positions in sentences) these findings held across all three languages, showing that noun learning is advantaged over verb learning even when verbs are more prominent within a language. Parallel findings were reported by Kersten and Smith (2002), who introduced 3.5-year-olds to a creature that moved in a unique manner while they heard either a novel verb or noun. When interacting with the same creature again, albeit moving in a novel way, children readily extended the noun to the new situation. Yet, when introduced to a new creature moving in the same manner, children did not extend the verb to the new situation. Similarly, Childers and Tomasello (2002) taught 2-year-old children several novel nouns or several novel verbs and tested their retention of the novel label over time. Their results showed that children retained the novel nouns but often failed to remember novel verbs. Interestingly, in empirical studies where children do succeed in learning novel verbs, it is often under experimental conditions that carefully scaffold verb learning. For example, increasing perceptual similarity between familiarisation and test exemplars (Childers, Paik, et al., 2016; Childers, Parrish, et al., 2016; Haryu et al., 2011), providing fewer exemplars during familiarisation (Maguire et al., 2008), giving children the opportunity to “re-enact” the novel action (Gampe et al., 2016), or by highlighting important components of the action with iconic gestures (Aussems & Kita, 2020; Mumford & Kita, 2014). Pairing verbs with iconic gestures or giving children the opportunity imitate an action previously paired with a verb is thought to help children overcome one of the challenges of verb learning; identifying which elements of a dynamic scene are relevant to the verb (see **1.1.2.2.** for a discussion of the “packing problem”; Mumford & Kita, 2014). On the other hand, increasing similarity across exemplars (or repeating exemplars) is proposed to help children abstract the relation between entities during an action rather than focusing on other salient features in a complex scene (Casasola, 2005).

Curiously, difficulty identifying and learning verbs is a problem for adults and children alike. In their “human simulation” project, Gillette and colleagues (1999) presented adult participants (i.e., experienced language users with large conceptual repertoires) with real video segments of mothers playing and speaking to their infants. Within each segment, participants were asked to identify a “mystery” noun or verb uttered by the mother. Importantly, the target noun or verb spoken was overlaid with an audible beep, and thus, participants needed to infer the meaning of the word from contextual information. Prior to guessing the word spoken, participants were exposed to the “mystery” word across several different situations to emulate cross-situational learning (Yu & Smith, 2007). The findings revealed that adults, like children, have a harder time identifying the intended referent of a verb. Adult participants succeeded in identifying the target verb only 15% of the time but, conversely, identified 45% of the nouns. Further, one third of the target verb items were never correctly identified, whereas all noun items were correctly identified by at least one participant in the sample. Seemingly, learning verbs is something that adults, like children, find hard even when provided with cross-situational exposures and despite having a lifetime of experience learning different types of verbs.

Figure 1.1
Sample stimuli from Imai et al. (2005, 2006, 2008)



Note: Sample stimuli from training and test trial. A) An example training stimulus with a novel action being performed on a novel object. B) A Same-Action-Different-Object test stimulus. C) A Same-Object-Different-Action test stimulus.

1.1.2. Why Verbs are Harder to Learn than Nouns

Not all words are learnt with the same ease; this much is clear. For children, noun learning is much easier than verb learning. But why are nouns privileged over verbs during word learning? According to theorists of lexical development, this disparity cannot be explained by intrinsic differences between word classes, but rather by the concepts that the words represent (Gentner & Boroditsky, 2001; Snedeker & Gleitman, 2004). That is, verbs tend to describe concepts that are abstract and relational by nature (Gentner, 1982; Gentner & Boroditsky, 2001), are challenging to identify in the world (Gleitman, 1990; Gleitman & Gleitman, 1992; Tomasello, 1995), and have more variable meanings across languages (Gentner, 1982). In the subsequent sections, I will briefly summarise these perspectives exploring why verbs are challenging to learn.

1.1.2.1 Natural Partitions Hypothesis

In her Natural Partitions hypothesis, Gentner (1982) proposes that referents of nouns are more accessible and readily identified than those of verbs, resulting in a noun learning advantage. Gentner describes how early learned nouns typically refer to objects and animate entities (e.g., people, animals) which are effortlessly individuated in the real world. These concrete entities are cohesive categories that have common properties among all members of the category (e.g., members of the *flower* category have a stem, stamen, and petals) and are lexicalised as nouns across languages. As such, these entities are perceptually stable, tangible, and, consequently, are mentally represented with ease (McDonough et al., 2011). The natural partitions hypothesis suggests that children more readily learn concrete nouns as they possess a transparent word-to-world link. That is, children form concrete object categories with ease and need only map a label onto their existing mental representations. Conversely, verbs denote relational concepts. These are concepts that are defined by the relation an object or animate being shares with itself or another entity (Gentner & Kurtz, 2005). Relational terms can take many forms; for example, they can be verbs (e.g., *drinking* describes the relation between a person and a container of liquid), prepositions (e.g., *above* describes where an entity is relative to another entity), or even nouns (e.g., *sister* describes the relation a person has with another person). Verbs describe actions and events which are inherently more abstract (i.e., limited information is available to the senses; Gentner & Asmuth, 2019) and ephemeral than the objects that nouns describe and, thus, are perceptually and cognitively more challenging to conceptualise.

Extending from this perspective, theorists have investigated the noun-verb learning debate by examining the concepts they denote along continuums of concreteness-abstractness and imaginability (Bird et al., 2003; Borghi et al., 2022; Gentner, 2006; Gentner & Boroditsky, 2001; Gillette et al., 1999; Maguire et al., 2006; McDonough et al., 2011). Within these viewpoints, children's propensity to learn nouns is a result of object categories typically being on the higher end of concreteness or imaginability. These accounts hypothesize that concrete, imaginable concepts first enter the lexicon and, thus, children's first verbs tend to be more concrete, observable actions too (Gentner, 2006). Imageability ratings of a word predicts children's age of acquisition for that word above and beyond its word class, suggesting that noun words' tendency to describe concrete, imaginable concepts is a likely cause for the noun bias (Ma et al., 2009; McDonough et al., 2011).

1.1.2.2 Relational Relativity and the Packaging Problem

The second claim in Gentner (1982) and colleagues' (Gentner & Boroditsky, 2001) theory argues that the meanings behind verbs are dictated by a language system and, therefore, the meanings of verbs vary more across languages than nouns do. Gentner and colleagues refer to this principle as linguistic or relational relativity (hereby referred to as relational relativity). Talmy (1975) first demonstrated that the information contained in motion verbs is shaped by a given language and not simply by the concepts they represent. The relational relativity account assumes that languages have many more degrees of freedom in how they label events than they do for objects, making verbs more challenging to learn. Therefore, when learning new verbs, children are faced with a "packaging problem" (Gleitman & Gleitman, 1992; Tomasello, 1995). Children need to identify the intended referent in real life scenes abundant with perceptual details that may or may not be relevant to the verb being spoken for the language system they use. That is, to identify a referent, children must already know what kind of semantic information is typically "packaged" within a verb for their language. For example, Germanic languages like English tend to incorporate *manner* into motion verbs (i.e., the distinct way in which an action is completed), Romance languages such as Spanish are more likely to contain details about *path* (i.e., the direction of movement), and some languages (e.g., Atsugewi, Navajo) also express details about the appearance of objects or materials moving during the action (Slobin, 1996, 2004; Talmy, 1975, 1985). From this perspective, verb learning is thought to be hard for children as they must first uncover how their language linguistically "packages" up (i.e., combines different perceptual information available in an event) different types of actions and events that verbs describe before verb acquisition can begin.

1.1.3. Verb Learning Paradox: Shifting Focus to Verb Comprehension

Despite having difficulty learning verbs, some verbs do nonetheless appear early in children's word production, with verbs like *eat* and *hug* being said before concrete nouns like *bed* and *cake* (Fenson et al., 1994). This discrepancy has previously been coined as the "verb learning paradox" (Maguire et al., 2006). That is, though verbs are harder for children to learn than nouns, some verbs are still acquired by children early in their lexical development. Evidently, though verb learning poses a demanding challenge for children, they do begin tackling the difficulty of mapping verbs onto actions early in life. How is it children come to learn some verbs early in their word learning journey? Potential insight into this question could be gleaned by focusing on how and when children come to comprehend verbs rather than focusing on their ability to say verbs. This receptive stage of language development serves as an important precursor to productive language and enables infants to recognise and respond reliably to early words before they can say them (Oviatt, 1980). For example, though most 1-year-olds can only say a handful of words, they typically already comprehend and recognise over 50 words (Fenson et al., 1994). We know that infants' understanding of concrete nouns (e.g., food items) begins early in the first year of life (~6-months-old) many months before the same words appear in children's productive language (Bergelson & Swingley, 2012; Parise & Csibra, 2012; Tincoff & Jusczyk, 1999, 2012). Yet, remarkably, descriptions of children's verb learning have largely been based on studies of children's word production but not their word comprehension (Goldfield, 2000). Early in this body of literature, Goldin-Meadow et al. (1976) noted that young toddler's verb production skills often underestimate their receptive verb knowledge. Testing children's receptive and productive language skills at home, the authors revealed that children understood many more nouns and verbs than they could say. In particular, children rarely said the verbs they knew though they produced many of the nouns they knew. As such, some insight may be gleaned by examining children's receptive language, which suggests that verb learning begins long before children say many verbs.

It is important to note at this point that the presence of verbs in children's comprehensive vocabulary need not suggest that that verb learning is easy for children. Indeed, the studies outlined above provide convincing cross-linguistic evidence that children struggle to lexicalise verbs in ways that they do not when learning nouns. Rather, our understanding of how children come to learn verbs is somewhat limited, especially given that much of the early research exploring children's word learning – that informed word learning theories – was focused on noun acquisition (Merriman & Tomasello, 1995). Thus, further investigation into children's verb comprehension will broaden understanding of children's verb learning journey and help to inform broader word learning theories.

These findings leave open two main questions; (1) how do children begin recognising verbs, and (2) when do children begin segmenting verbs from speech and linking verbs with their referents. Here, I will review evidence that provides an overview of the theoretical and empirical research exploring these questions. I begin by addressing the first question, discussing core theories of word learning and how they inform our understanding of children's verb acquisition. To shed light on the second question, I then review literature that has explored when infants begin developing some of the linguistic, cognitive, and conceptual capabilities that support verb learning.

1.2. How Children Learn Verbs: Theories of Word Learning

When a word is spoken, there are limitless potential meanings of the word including objects, people, events, a specific property of an entity, and so on. This issue, notably described by Quine (1960), is known as the "reference problem" (Rowland, 2013). Quine gives an example of a linguist interacting with a native speaker of a different language who says "Gavagai!" as a rabbit runs past them. Does this word refer to the "rabbit", label the act of the rabbit running away, or describe the colour of the rabbit's fur? This scenario persuasively articulates word learning challenges also faced by children as naïve language learners. That is, in a given scene, there are many potential word-to-world mappings. How does a child narrow down the possible referents of the word? Theories of word learning attempt to answer this question to describe *how* children learn words. Here, I outline the fundamental tenets of several theoretical perspectives and how these mechanisms can support early verb learning.

1.2.1. Constraints Theories

Constraint approaches suggest that young word learners use of a series of innate "constraints" or cognitive biases to reduce the number of predictions regarding a word's meaning (Nelson, 1988). That is:

> The way children succeed in acquiring [words] so rapidly is that they are limited in the kinds of hypotheses they consider. Children do not always have to reject hypotheses on the basis of negative evidence. They can implicitly reject them by being biased against them in the first place. (Markman, 1990, p. 58).

Within this perspective, three specific constraints were proposed to guide children's early interpretations of novel words; namely, the whole object assumption, the taxonomic assumption, and the principle of mutual exclusivity. The whole object assumption suggests children assume that novel labels refer to whole objects rather than part of an object or an object property (e.g., texture, colour; Markman, 1990). The taxonomic assumption describes how children begin extending labels for objects that they have learnt. This assumption posits that to learn the meaning of a word, children extend new labels to other referents that belong to the same category (i.e., taxonomic grouping) rather than to referents that are thematically related (Hall & Waxman, 1993; Markman & Hutchinson, 1984). For example, a child that has learnt the word for "cup" will extend the word to other different teacups rather than thematically related objects (e.g., teapot). The principle of mutual exclusivity suggests that children assume every object only has one name (Markman et al., 2003; Markman & Wachtel, 1988; Merriman et al., 1989). It is thought that mutual exclusivity helps children to learn names for new objects they encounter but also assists them in moving beyond the whole object bias (once they know the label for that object) to begin learning names for object properties, parts, and non-object labels. Other principles comparable to mutual exclusivity also hypothesise that children use differences between objects to assign new labels (contrast principle; Clark, 1983, 2007). However, mutual exclusivity is not universal for all children and can be over-ridden when children are exposed to multiple languages. In fact, bilingual children (and bilingual adults) will readily accept two names for the same object when a name for the object is provided in both native languages (Au & Glusman, 1990).

One prominent criticism of constraints theories is that they fail to describe how children come to learn words other than nouns (Tomasello, 1995; Tomasello & Merriman, 1995). This is particularly problematic given that children's earliest learned words feature words from across all word classes (Nelson, 1973). To address this, Golinkoff and colleagues (1994, 1995) proposed six additional constraint principles (some overlapping with prior proposed constraints) that explain word learning beyond just words for objects and consider learned, as well as innate, biases. Golinkoff et al.'s developmental lexical principles are organised into two tiers. First, the principles of reference (children assume words map onto concepts of objects, actions, and attributes), extendibility (labels extend to multiple exemplars for each category that are often perceptually similar), and object scope (words often map onto objects, especially whole objects) describe essential skills necessary for slow, early word learning. Second, children later develop a second tier of principles as they become more experienced word learners. Namely, the principles of categorical scope (new words can be extended to other basic level category members), novel name-nameless category (new labels refer to object or action categories that do not yet have a name), and conventionality (words must align with those used by other speakers and the broader linguistic community;

inspired by Clark, 1983, 2007). Golinkoff et al. (1995) describe that whilst the developmental lexical principles were initially considered as descriptions of children's noun learning biases, they can be readily transferred to describing biases supporting verb learning. Even the principle of object scope (that presumes children interpret novel words to describe whole objects) is thought to support verb learning by helping children assign novel labels to actions in the presence of known objects.

Constraints theories and lexical principles are an attractive approach to word learning theories. Namely because they propose explanations of word learning that are seemingly innate and universal, which is useful for understanding how young infants with limited linguistic experience may come to understand words during the first year (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012). Whilst there is empirical support for cognitive word learning biases (e.g., Golinkoff et al., 1996; Markman & Hutchinson, 1984; Markman & Wachtel, 1988), studies show that these principles rarely explain cross-linguistic differences in word learning (e.g., Choi & Gopnik, 1995; Gopnik et al., 1996; Tardif, 1996; Tardif et al., 2008), often ignore cognitive domain-general learning processes (Spencer et al., 2009), and were largely developed to explain noun acquisition (Merriman & Tomasello, 1995). As such, many other theoretical approaches to word learning have sought to focus on broader social-cognitive processes that also consider how verbs are acquired.

1.2.2. Social-Pragmatic Account

The constraints approach assumes children exploit a series of in-built biases that narrow down the meaning of novel words. In contrast, the social pragmatic account of word learning argues that children utilise social-cognitive skills to determine the intentions behind a speaker's words and actions (Akhtar & Tomasello, 2000; Nelson, 1988; Tomasello, 1992b, 1995). This viewpoint emphasises the social nature of language and proposes that the challenge of word learning is less about establishing the referent of a novel word, but rather, discerning what another speaker is trying to communicate. The social pragmatic account is thought of as a useful approach for understanding verb learning in particular as the referents of verbs tend to only be perceptually accessible for brief periods of time and, thus, children must rely on other communicative cues provided by the speaker when the referent is absent. For example, as Tomasello and colleagues (1995; Tomasello & Kruger, 1992) demonstrated across several experiments, infants often hear verbs in non-ostensive situations with parents saying verbs in anticipation of an action occurring more so than during or after the action is completed. Indeed, the authors showed that two-year-old children can learn a novel verb without the referent being visually available at the time of labelling. Since, several studies have indicated that children utilise social information available during novel verb learning contexts to determine the meaning of the verb (e.g., gaze, intentions, gestures). For example, one way infants and children can determine a speaker's referential intent is by following the speaker's gaze (i.e., joint attention; Scaife & Bruner, 1975). By 10 months, infants can follow an adult's gaze to ascertain what is catching their attention (Brooks & Meltzoff, 2005). For example, Brooks and Meltzoff (2005) demonstrated that 10- and 11-months-old (but not younger) infants followed an experimenter's head turn towards a target object, but only when the experimenter's eyes were open. Infants' gaze following skills were also positively associated with their later word comprehension skills (Brooks & Meltzoff, 2005) and speed of vocabulary growth (Brooks & Meltzoff, 2008). In verb labelling situations, young word learners follow the gaze of adult speakers and use the direction of gaze to guide their interpretation of a verb (Nappa et al., 2009; Poulin-Dubois & Forbes, 2002). Interestingly, a recent meta-analysis of 60 different studies (849 children between 14- and 42-months-old) found that gaze following had the strongest impact on verb learning compared to other verb learning mechanisms (e.g., mutual exclusivity, syntactic bootstrapping; Cao & Lewis, 2022).

Children also use a speaker's intentions to understand the meaning of a novel word, which can be used to differentiate whether the novel word refers to an action or an object. For example, Tomasello and Akhtar (Study 2; 1995) showed 2-year-old children an unnamed object being used to complete an unnamed action which was labelled with a novel word. Whilst all children saw the experimenter complete the novel action, only some children then saw the experimenter set up the apparatus ready for the action to be completed again. The experimenter then looked back and forth between the child and the apparatus, indicating their intention for the children to perform the action. In contrast, the other children saw the experimenter pick up the object, after demonstrating the action, before the experimenter began looking back and forth between the child and the object. Interestingly, children who saw the apparatus set up ready for an action to be performed mapped the novel word onto the action, whereas the other children (whose attention was drawn to the object) mapped it onto the object.

Gestures may also help children to infer the meaning of new verbs. Speakers may use gestures to make the meaning of a word more salient to a child. Indeed, even infants understand that gestures (especially deictic gestures), like words, are referential in nature (Gliga & Csibra, 2009). With verbs, where the referent is abstract and can contain variable information (e.g., manner, path), gestures can guide children's attention to elements of an action that are relevant to the verb. For example, three-year-old children readily adapt their interpretation of a novel verb to align with the type of gesture they are exposed to, such as deducing a novel verb as a manner verb when seen alongside a manner gesture (Mumford & Kita, 2014). Such gestures also support children's generalisation of new verbs to novel situations (Aussems et al., 2021; Aussems & Kita, 2020). Nonetheless, attention to social cues alone cannot explain early word learning (Akhtar & Tomasello, 2000). Indeed, the social pragmatic approach acknowledges the need for other processes involved in word learning such as attention and associative learning across multiple word-world exposures.

1.2.3. Associative Learning

Associative learning is a fundamental domain-general mechanism by which information about relations in the world are gleaned through exposure. Advocates of associative learning accounts claim that the words infants learn emerge out of statistical regularities identified by "dumb attentional mechanisms" (Smith, 2000; Smith et al., 1996). That is, children gradually use combinations of general cognitive processes of perception, attention, and memory across labelling scenarios to link words with their referents (Samuelson & Smith, 1998). Over time, children begin to link labels with referents that frequently co-occur together. For example, imagine that the word "apple" is most often heard in the presence of objects that are apple shaped and rarely heard when an apple is not present. Eventually, children will begin associating the word "apple" with objects that look like apples before learning to lexicalise these objects as "apples". In the context of noun learning, this process has previously been termed "the Shape Bias" (Landau et al., 1988; Smith et al., 2002). That is, children's propensity to initially acquire nouns is because they learn, by association, that objects that look the same tend to have the same name.

Within this account, the act of initially linking a label with a referent is first governed by automatic, bottom-up attentional processes that guide children to focus on the most salient or novel aspect of a scene (e.g., salient action or novel object; Smith et al., 2003). From this, children's memory plays an important role across their exposures to a word-world mapping, retrieving memories about these pairings over time (Vlach & Sandhofer, 2012). Specifically, the associative learning approach places importance on children's ability to engage in cross-situational learning (Smith & Yu, 2008; Yu & Smith, 2007). Cross-situational learning refers to the ability to store possible word-referent pairings in memory, across exposures in different contexts, and use statistical regularities that emerge (i.e., commonalities across contexts) to map a word onto a referent. With nouns, infants as young as 12-months-old have been found to use statistical evidence from across multiple ambiguous labelling contexts to learn the word for a novel object (Smith & Yu, 2008). Researchers have also long assumed some form of cross-situational learning is present in verb acquisition (Childers et al., 2018). Indeed, these studies show that 2.5-year-old children track consistencies between a verb and action across multiple exposures (Childers, 2011; Scott & Fisher, 2012) which has been reported cross-linguistically for English, Korean, and Japanese speaking children (Childers & Paik, 2009; Haryu et al., 2011).

1.2.4. Syntactic Bootstrapping

One of the primary mechanisms proposed to explain verb learning, known as "syntactic bootstrapping", proposes that children use syntactic information to infer the meaning of a novel verb (Brown, 1957; Gleitman, 1990; Naigles, 1990). Verbs determine the number and type of roles to be played by other words in the sentence. For example, transitive verbs tend to describe a participant's action on an object or other participant, whereas intransitive verbs describe a participant's action alone without an object or other participant. These different verb types are also associated with specific sentence structures with transitive using two noun phrases (e.g., "Sally *pushed* John") and intransitive using one (e.g., "Sally *jumped*"). Syntactic bootstrapping builds on the fact that there are statistical regularities between sentence structure and semantic information contained within a given verb, to which children are implicitly sensitive (Naigles, 1990). For example, if a child hears the sentence "Look! The dog is *blicking* the ball!", the account predicts that the child can use syntax, knowledge of other words in the sentence, and information present in an observed scene to narrow down the meaning of the word. Here, the child could use the transitive structure (where the verb refers to an action being performed on an object or person) and knowledge of other words in the sentence (e.g., "ball") to narrow down that the novel verb likely refers to an action being completed by a known participant (i.e., the "dog").

Gillette and colleagues' (1999) study provided clues that observing a complex scene and attending to social cues alone are likely not sufficient for verb learning. While watching silent videos of mothers playing with their infants, adults often failed to guess what verb might have been said by the mother to the child. For example, participants saw a short clip when a mother had said "*show* me your truck" (though watched the video in silence and did not hear the sentence) and then the child raised their truck towards their mother. The participants had to guess which verb would have been said by the mother (i.e., show) and generally failed to guess the correct verb. However, when additional syntactic information was included (e.g., participants heard the sentence while watching the video with the verb replaced with a nonsense word) participants were more likely to accurately guess the meaning of the verb. Thus, additional mechanisms, such as syntactic bootstrapping, may be necessary to identify the meaning of a novel verb. Evidence of this process in developmental populations come from children assuming different meanings of a novel verb when uttered in different syntactic structures (see Fisher et al., 2010, 2020, for reviews). For example, Naigles (1990) presented 2-year-old children with two simultaneous videos of different actions being performed by the same characters (a rabbit and a duck). In one video, one character was performing an action on the other (e.g., duck lifts rabbit's leg) and the other video showed the characters separately performing the same action (e.g., duck and rabbit make arm circles). Half of the children heard a transitive sentence alongside this ("the duck is *gorping* the bunny!"), the other half heard an intransitive sentence ("the duck and the bunny are *gorping*!"). Children who heard a transitive sentence looked longer at the action being performed on another character whereas children who heard an intransitive sentence looked longer at the actions being performed separately. Simply, children assigned the meaning of the verb on the basis of the syntactic structure. Indeed, even infants seem to use rudimentary forms of syntactic bootstrapping. Like previous designs (e.g., Naigles, 1990; Yuan et al., 2012), Jin and Fisher (2014) showed 15-month-olds simple side by side videos of two separate actions: a two-participant action (e.g., a box bumping into another box) and a one-participant action (e.g., a ball bouncing up and down). Trials were either accompanied by a transitive sentence (e.g., "he's *kradding* him!"), an intransitive sentence (e.g., "he's *kradding*"), or a neutral statement (e.g., "Which is your favourite?"). Infants looked longer at the two-participant action when hearing a transitive sentence compared to the other sentences, suggesting that, by 15 months, infants interpret novel verbs on the basis on syntax. However, a recent meta-analysis of verb learning mechanisms revealed that, despite being a central theoretical explanation of verb learning, syntactic bootstrapping had a small effect size on verb learning across studies (Cao & Lewis, 2022).

1.2.5. Summary of Word Learning Theories

Here, I discussed several word learning theories and described studies that provide insight into how these mechanisms may explain early verb learning. Broadly, constraints theories suggest children have "in-built" cognitive biases that help narrow down the meaning of a word, whereas the social-pragmatic account proposes that children use social-cognitive skills to infer word meanings from social cues provided by a speaker. In contrast, associative learning accounts assume that children use powerful domain-general cognitive skills to recognise which words and referents often appear together over many exposures. Finally, syntactic bootstrapping claims that children use syntactic structures to infer a novel verb's meaning. It is important to note that whilst some of these theories seek to explicitly explain the acquisition of verbs (e.g., syntactic bootstrapping, social pragmatics), other perspectives have initially focused on explaining how children acquire nouns (e.g., constraints, associative learning). As such, some theoretical perspectives have less empirical support for these mechanisms in the case of verb acquisition. Explanations for early word learning continue to be fiercely debated, with each mechanism alone failing to explain the complex issue of word learning, especially for lesser studied words such as verbs, adverbs, and adjectives. Recent reviews of word learning mechanisms suggest that, in the case of verb learning, several different (and possibly interacting) mechanisms are likely at play to understand such complex and abstract referents (Childers et al., 2018). For example, the emergentist coalition model presents as a hybrid model of word learning that considers how children may weight several mechanisms and cues (i.e., perceptual salience, word-referent co-occurrence, syntactic information, social context, eye gaze, and prosody) to learn nouns (Hirsh-Pasek et al., 2000) and verbs (Golinkoff & Hirsh-Pasek, 2008). Yet, such theoretical perspectives that propose the use of many interacting mechanisms may be challenging to adopt as they are hard to falsify (i.e., most data outcomes will in some way align with some of the theoretical predictions; Rowland, 2013).

1.3. Linguistic, Cognitive, and Conceptual Prerequisites to Verb Comprehension

Outside of specific word learning mechanisms, theorists suggest that verb learning builds on three core skills. Namely, the ability to (1) identify a verb (finding a verb within continuous speech), (2) form an action concept (attending and categorising actions), and (3) map a verb onto an action or event (Gentner, 1982; Golinkoff et al., 2002). Before verbs are lexicalised, one approach to predict the age by which children may comprehend their first verbs is by examining when infants evidence these cognitive and conceptual prerequisites that lay the groundwork for verb learning to occur. I now describe each of these developing capacities in turn, with empirical evidence from across the first year of life.

1.3.1. Finding the Verb: Identifying Words in Continuous Speech

To determine the potential period in which infants begin linking verbs with actions, it is first necessary to ascertain when the perceptual underpinnings associated with word identification are available to infants. Yet, this is no small task. Before infants begin finding word forms in the speech stream, they must first be able to recognise differences between speech and non-speech, perceive smaller units of speech (e.g., phonemes), and hone-in on speech sound characteristics associated with their native language/s (e.g., rhythmic, stress). Before they have even acquired experience listening to speech outside the womb, at approximately 29 weeks gestation, infants are equipped with adult-like speech processing neural structures and functioning that are thought to aid language acquisition (Dehaene-Lambertz et al., 2008). From birth, infants display language processing skills as a consequence of *in utero* listening experience. For example, infants show a preference for speech over non-speech and even a preference for their own language over an unfamiliar language (Mehler et al., 1988; Moon et al., 1993; Vouloumanos & Werker, 2007). Interestingly, infants with bilingual prenatal experience (i.e., frequently hearing two languages *in utero*) respond equally to both of the languages they were exposed to (Byers-Heinlein et al., 2010). Additionally, newborn infants prefer the speech of their mother over that of a stranger (Decasper & Fifer, 1980; Spence & Freeman, 1996). Together, these findings demonstrate that, in the first days of life (and even before), infants have begun "tuning in" to speech and developing preferences for speech that is familiar.

Young infants also show impressive phoneme perception abilities, initially discriminating between many of the consonants of the world's languages (see Maurer & Werker, 2014, for a review). For example, Eimas et al.'s (1971) seminal study revealed that very young infants (~1- to 4-months-old) differentiate between similar sounding syllables /b/ and /p/ (often perceived as /ba/ and /pa/) and can even discriminate speech sounds that they do not yet have listening experience of (e.g., Streeter, 1976; Werker et al., 1981; Werker & Tees, 1984), something that adults struggle to do outside of their native language. As listening experience and sensitivity to one's native language increases, abilities to discriminate between other languages consonants, vowels, and lexical tones declines (between approximately 6- to 10-months-old), a phenomenon known as "perceptual narrowing" (Maurer & Werker, 2014; Werker & Tees, 1984). At this time, around 10-months-old, infants' perception of speech sounds associated with their native language strengthens, thought to reflect a reduction in neural plasticity whereby infants can no longer respond and adapt to other languages with the same degree of ease (Werker & Hensch, 2015).

As infants acquire the sound characteristics of their native language, they also gain the ability to extract the sound patterns associated with a word unit from the speech signal, commonly referred to as word segmentation. Word segmentation is a challenging task that largely involves finding the boundaries between individual words by figuring out where the gaps or pauses lie within speech. As young as 7.5-months-old, infants are reported to segment small monosyllabic words from long passages of speech (Jusczyk & Aslin, 1995). How do infants learn to extract words from speech? Several studies suggest that cues within speech support infants in the process of identifying words within speech: prosodic cues (stressed syllable patterns and rhythms within speech; Jusczyk, Houston, et al., 1999), phonotactic information (language specific limitations on phoneme order; Mattys & Jusczyk, 2001), allophonic cues (variations of how different phonemes are pronounced as a function of word position; Jusczyk, Hohne, et al., 1999), statistical regularities (tracking the probability of specific syllables occurring together; Saffran et al., 1996) and known words.

Languages tend to have specific rhythmic patterns that dictate when syllables are stressed and when pitch fluctuates, giving rise to prosodic cues. For example, English follows a predominantly trochaic pattern with approximately 90% of words starting with strong syllables and ending with weaker syllables (e.g., PENcil, DOCtor; Cutler & Carter, 1987) which infants could exploit to segment words (Cutler & Norris, 1988). Studies with English hearing infants shows that, indeed, 10.5-month-olds use these predictable variations in syllable stress to find the onset and offset of words within speech (Jusczyk, Houston, et al., 1999). However, though use of such mechanisms has also been found for Dutch (Houston et al., 2000) and Canadian French (Solé & Recasens i Vives, 2003), this pattern is not always found cross-linguistically (e.g., Nazzi et al., 2006). Around the same age, infants also seem to exploit allophonic (Jusczyk, Hohne, et al., 1999), phonotactic (Mattys & Jusczyk, 2001), and statistical regularities in syllable combinations cues (Saffran et al., 1996) to identify word boundaries. Together, these findings suggest that between 7- and 10-months, infant likely use a combination of these language-specific and general speech cues to segment words.

Across these studies, the researchers explored these mechanisms using noun stimuli. These findings also broadly align with looking time studies that show infants can identify and comprehend several early nouns between 6- and 9-months-old (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012). What about verbs? Interestingly, whilst studies show that English nouns tend to have strong-weak syllable patterns (Cutler & Carter, 1987), the opposite is true for English verbs that mostly follow a weak-strong syllable pattern (Kelly & Bock, 1988) which may be challenging for young word learners. Nazzi and colleagues (2005) colleagues tested this prediction directly with infants aged 10.5-, 13.5-, and 16.5-months-old in a head turn preference paradigm. Infants were familiarised with target verbs before being presented with passages either containing the target verbs or novel verbs. The authors found that only infants aged 13.5 months or older were able to segment the familiarised verbs from the passages of speech. They also reported that verbs starting with vowels and with a weak-strong syllable stress pattern were most challenging for infants to segment. The authors concluded that the delay in saying verbs may, in part, be due to difficulties in verb segmentation that infants only begin overcoming after 10.5-months-old. However, it is important to note that, unlike previous word segmentation studies, Nazzi et al. (2005) used word stimuli that are highly abstract and known to be acquired late in development. For example, Jusczyk, Houston, et al. (1999) used noun items that feature in standardised checklist measures whereas few of Nazzi et al.'s (2005) items feature in such checklists. As such, infants may have been particularly unfamiliar with these word tokens that are less likely to be heard in their day-to-day life.

1.3.2. Forming Action Concepts

Segmenting a verb from speech provides infants with the linguistic form of a verb that they can link with an associated action. Yet, infants must also attend to an action, individuate it from other actions, and form an action category (i.e., conceptualisation) before a verb can be mapped onto it (Golinkoff et al., 2002). From the very first moments of life, infants are drawn towards actions and motion. In their first few hours, newborn infants attend to movement over stationary displays (Slater et al., 1985). A few months later, infants can discriminate between biological and non-biological motion (Sifre et al., 2018), and will preferentially attend to actions over other salient stimuli (e.g., faces; Bahrick et al., 2002; Bahrick & Newell, 2008). From 6-months-old, infants demonstrate impressive action segmentation skills, extracting distinct movements from streams of continuous movement (Sharon & Wynn, 1998; Spelke, 1976; Wynn, 1996). For example, Wynn (1996) habituated 6-month-olds to a puppet jumping two or three times. At test, infants looked longer to the puppet that jumped a novel number of times. From this age, infants also begin to process violations of familiar action sequences, demonstrating an ability to recognise individual segments within continuous action (Baldwin et al., 2001; Maffongelli et al., 2018; Monroy et al., 2019). For example, 10- to 11-month-olds were familiarised with sequences of an everyday action such as an adult picking up a container of food and walking towards the fridge (Baldwin et al., 2001). During test trials, infants saw the same sequences with short pauses that occurred either during the action or when the action was completed. Infants looked longer to sequences that were paused during the action sequence (i.e., interrupting the action structure) compared to when the video paused after the action had been completed. Thus, by approximately 10-months-old, infants are sensitive to action boundaries and can parse ongoing movement into action segments. Such understanding may initially arise from learnt statistical regularities after repeated observations of others' goal-directed actions that help infants learn about action structures (Hunnius & Bekkering, 2014; Ruffman et al., 2012).

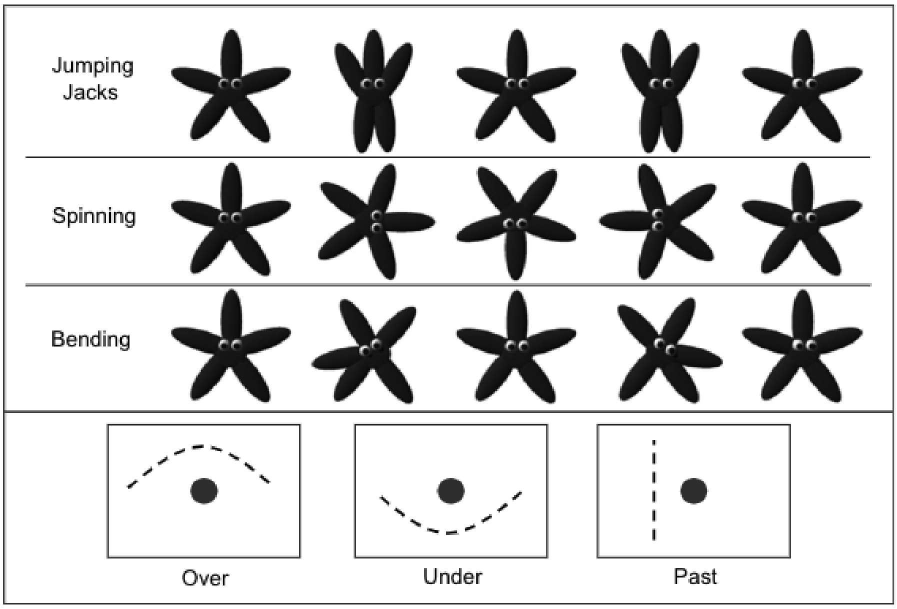
Skills in action parsing also serve as important precursors to action understanding and recognising another's actions as organised by their intentions. That is, action understanding describes the ability to analyse a person's action to understand their intent. Action understanding is not only a fundamental skill for making sense of other people's actions but also in building foundational knowledge of actions which children will later map verbs onto (Behrend & Scofield, 2006). Indeed, many of the first verbs that children lexicalise describe the concrete and observable actions that infants witness others doing in their everyday lives (Sootsman Buresh et al., 2006). Evidence from many studies shows that the ability to understand actions as intentional and goal directed develops in the first year of life (see, de Moor & Gerson, 2020; Woodward et al., 2009, for reviews). Infants already preferentially attend to the goal structure of an action between 3- and 6-months-old and develop more sophisticated goal recognition skills over time (e.g., Biro & Leslie, 2007; Gerson & Woodward, 2014; Sommerville et al., 2005; Woodward, 1998). For example, once familiarised with a goal-directed action (i.e., reaching for one of two toys), 6- and 9-month-old infants will show renewed interest when the goal of the action is altered but not when the path of reaching changes (Woodward, 1998). That is, infants recognised the action in terms of its goal structure, instead of motion, indexed by recaptured attention at test. These findings have also been replicated using eye-tracking paradigms (Cannon & Woodward, 2012). Infants' understanding of actions also plays an important role in verb learning. Recognising actions as intentional and goal-directed may help infants organise their action concepts prior to the emergence of verb learning (Sootsman Buresh et al., 2006). Figuring out which elements of an action are conveyed in a verb is challenging for children and highly variable across languages (Gentner, 1982; Gentner & Boroditsky, 2001; Gleitman & Gleitman, 1992). Knowledge of actions provides infants with an understanding of the components of action that are relevant to achieving a goal and the components that will be lexicalised in a verb (Sootsman Buresh et al., 2006). For example, reproducing an action after hearing a novel verb has been found to help young children learn the novel verb (Gampe et al., 2016).

Further, as previous described, recognising and understanding the intentions of other people is also a fundamental skill involved in inferring the meaning of a novel verb (Akhtar & Tomasello, 2000; Nelson, 1988; Tomasello, 1992b, 1995).

Beyond understanding actions, infants must also form mental categories of actions, taking the form of action concepts, that motion verbs will subsequently be mapped onto (Golinkoff et al., 2002). Categorisation, in word learning, refers to the ability to recognise and respond equally to the commonalities that exist between a broad range of referents that belong to the same group. Yet, categorising actions requires infants to discriminate and conceptualise different relational components of events and motion (Göksun et al., 2011). Linguists and cognitive scientists alike have described several motion components that are encompassed in motion verbs (and other relational terms; Talmy, 1975, 1985) or within infants' relational concepts (Mandler, 2006). Talmy defined several aspects of motion that can be linguistically decomposed into components that verbs often describe such as *manner* (the way in which an action is performed: Jane could either "run", "walk" or "skip" to school), *path* (the trajectory in relation to a reference point: John could either go "under", "over" or even "around" the bridge), *figure* (encodes the agent or object of focus), and *ground* (the stationary point of reference or entity of reference). On the other hand, Mandler describes how children come to develop image schemas (i.e., prelinguistic concepts of spatial and relational structures that are derived from infants' perceptual experiences) that support infants' fundamental understanding of motion and movements across space. Here, notions of relations such as *path* (see Talmy, 1985), *containment* (an entity within enclosed space), and *link* (relations between components of events) help infants to understand animacy, causality, and agency. Within these perspectives, infants' initial ability to categorise components of actions into distinct concepts of motion supports their later detailed action concepts.

Several studies demonstrate that the ability to discriminate between different motion components and develop categories of these distinct components is present within the first year of life. Across a series of studies, a set of stimuli displayed a cartoon starfish that performed an action containing a manner and a path (see **Figure 1.2**; Pulverman et al., 2006) to explore infants' motion discrimination and categorisation skills. For example, using habituation paradigms, 7- to 9-month-old and 14- to 17-month-old infants were familiarised with the starfish performing an action using a consistent manner and path (e.g., spinning over an object; Pulverman et al., 2008, 2013). At test, infants saw actions that maintained one of these factors and changed the other (e.g., spinning *under* an object maintains the manner, from the example above, but changes the path). At both ages, infants detected both changes in path and manner, suggesting that as early at 7-months-old, infants can discriminate and process components of motion separately. Additional studies also show that by 13- to 15-months-old, infants demonstrate sophisticated event processing skills, readily forming categories of different manners (Pruden et al., 2012). In one experiment, Pruden and colleagues (2012) familiarised 10- to 12-month-old and 13- to 15-months-old infants with a cartoon character completing different actions that all involved a common manner but carried out across different paths. At test, infants saw two videos of the starfish, side- by-side, with novel paths: one video retained the manner during familiarisation and the other presented a novel manner. Thirteen- to 15-month-olds looked longer at the novel event, indicating that they detected the change in manner, because a manner category had been violated, whereas 10- to 12-month-olds showed no preference for either video. The authors argued that the younger infants may have found the stimuli too cognitively demanding as infants were required to simultaneously attend to the action's path, manner, and ground (i.e., the static point of reference).

Figure 1.2
Stimuli from Pulverman et al. (2006)



Note: The first three rows depict different motion manners used across the experiment, which the starfish cartoon performed along one of the specified paths shown in the bottom row.

In a second study, the authors showed that 10- to 12-month-olds could successfully categorise an action's manner when the number of motion components was reduced by removing information about the ground component. Later studies furthered these findings by revealing that 10- to 12-month-olds can also categorise path motions (Pruden et al., 2013). Together, this body of work suggests that from 10-months-old, infants can discriminate different motion components and evidence the ability to categorise motion under supportive conditions, laying the foundations for later verb learning. Indeed, studies have also revealed that individual differences in these early event processing abilities are predictive of children's later verb comprehension and production (Aktan-Erciyes & Göksun, 2019; Konishi, Stahl, et al., 2016a).

1.3.3. Mapping Verbs to Actions

Previous research shows that within the first year of life (~10-months-old) infants have begun segmenting words from continuous speech, discriminating between discrete actions, understanding intentions behind actions, and categorising components of motion. These cognitive and conceptual capacities lay the essential groundwork for verb learning. Yet, to learn a verb – or indeed any word – infants must link a label with a relevant concept. As I outlined earlier in this chapter, *how* children begin associating novel verbs with actions is highly debated. Here, I describe studies exploring *when* children begin associating words with their referents. Studies have explored children's word-referent mapping capabilities using observational or parent-report methods (e.g., Benedict, 1979; Fenson et al., 1994), by training infants with novel words in the lab (e.g., Gogate & Maganti, 2017; Stager & Werker, 1997; Werker et al., 1998) and by measuring their existing word knowledge. Here, I describe several studies using empirical methods that demonstrate how infants can link nouns and objects early in development, before describing work that has begun exploring when infants can extend this ability beyond nouns.

Several studies have shown that infants understand some concrete nouns as early as 6-months-old. For example, across two studies, Tincoff and Jusczyk (1999, 2012) used an intermodal preferential looking paradigm (Golinkoff et al., 1987) to explore noun comprehension in 6-month-old infants. In one study, infants were presented with videos of their mother and father, paired either with "mommy" or "daddy" (Tincoff & Jusczyk, 1999). The authors reported that infants looked longer at the video of the named parent, suggesting that at 6 months, infants uniquely associate the labels for each parent with the correct parent. In the other, using the same paradigm, infants saw novel video exemplars of adult hands and feet while they were labelled (i.e., "hand", "feet"), and were found to look longer at the video that matched with the label (Tincoff & Jusczyk, 2012). More recently, Bergelson and Swingley (2012) used an eye-tracking adaption of a looking while listening paradigm (see

Chapter 2 for an overview; Fernald et al., 2008; Swingley, 2011) to explore infants' receptive noun knowledge and found that infants aged 6- to 9-month-olds already understand several nouns for food items and body parts (see Bergelson & Swingley, 2015, for replication with video stimuli). Analogous findings have also been reported using event-related potentials (ERPs) with 9-month-old infants (Parise & Csibra, 2012). Together, these studies show that by 6-months-old, infants have already begun associating common nouns with concrete objects. Several studies have also reported that between 6- and 14-months-old, infants can learn novel word-object or syllable-object pairings in lab settings (e.g., Gogate et al., 1998, 2006; Henderson & Woodward, 2012; Matatyaho & Gogate, 2008; Shukla et al., 2011; Smith & Yu, 2008; Werker et al., 1998). For example, Shukla and colleagues (2011) presented 6-month-olds with three objects; two static distractor objects and a target object that moved (drawing infants' attention to that object) while infants heard short utterances that contained a novel word embedded amongst other syllables. At test, infants saw the same three objects looming on a screen while the novel word was uttered in isolation and looked significantly longer at the target object, suggesting that they learning the meaning of the novel utterance.

The items tested in the aforementioned studies represent highly concrete referents, which theorists have suggested are easier for children to individuate and conceptualise than verbs (Gentner, 1978, 1982, 2006; Gentner & Boroditsky, 2001). As discussed above, for abstract and relational words like verbs, it is likely children would understand these words later in development. Two studies using designs based on Bergelson and Swingley (2012) have begun exploring when infants begin linking abstract words with their referents (see Chapter 2 for an in-depth description of these studies; Bergelson & Swingley, 2013; Nomikou et al., 2019). Bergelson and Swingley (2013) tested 6- to 9-month-old, 10- to 13-month-old, and 14- to 16-month-old infants' understanding of abstract referents including some phrases (e.g., "all gone"), adjectives (e.g., "wet"), and verbs (e.g., "eat"). The authors reported that only 10- to 13-month-olds and older infants looked significantly longer at target items in the task. One additional study by Nomikou and colleagues (2019) tested whether 9- and 10-month-old infants linked verbs with images of objects that are frequently involved in specific actions. Specifically, infants were presented with photos of objects involved in daily care routines (e.g., building blocks, a banana) and tested whether infants linked verbs associated with routine actions (e.g., "building", "eating"). Ten-month-olds, but not 9-month-olds, looked longer at target items across trials. Few experimental studies have sought to explore whether infants can be taught novel verb-action pairings before infants begin speaking but Gogate and Maganti (2017) demonstrated that 8- and 9-month-old can pair novel words with simple motions. In this study, Gogate and Maganti (2017) habituated 8- to 9-month-olds to two simple movements on an object (shaking an object, looming an object) paired with nonsense monosyllabic words. During test trials, infants saw the same actions but with the label switched. Infants looked longer after the items were switched, suggesting that infants had paired the novel words with the action. Together, these studies suggest that infants understand some abstract words and can pair words with actions by 10-months-old, around the time that more sophisticated word segmentation and event processing skills emerge. However, when infants start understanding the meanings of their first verbs is still unclear as these studies either did not directly assess infants' verb understanding with action exemplars (e.g., only examining whether infants linked verbs with photos of objects; Nomikou et al., 2019), included too few verb stimuli, or included too wide of an age range to make broader conclusions about the onset of verb comprehension (Bergelson & Swingley, 2013).

1.3.4. Summary of Prerequisites for Verb Learning

Before infants can learn a verb, there are several tasks that they must tackle (Gentner, 1982; Gentner & Boroditsky, 2001, Golinkoff et al., 2002). Namely, children must first develop cognitive capacities necessary for word segmentation and conceptualisation of actions. Foremost, infants must be able to identify a label within a speech stream. Infants also need to process events by parsing individual actions from continuous flows of motion, understand other's actions as intentional and learn to discriminate and categorise the relational components that make up an action. Finally, infants must bring these together in order to map verbs onto actions. From this, it can be inferred that children's slower acquisition of verbs stems from three potential origins: (1) inability to segment words in speech, (2) difficulty making sense of actions, or (3) trouble linking verbs with action categories. In this section, we have seen that infants start attuning to their native language early in life, but only begin consolidating phonemes and segmenting words from their native language around 10-months-old. Within this period, infants are also learning about other's actions and beginning to form concepts of actions. These skills seemingly also support infants to overcome the "mapping dilemma" by mapping nouns and some abstract words with their referents, something which Genter (1982) suggests is most challenging for children.

Thus, together, this body of literature suggests that the ability to understand verbs may emerge around 10-month-olds. In this thesis, I aim to test this hypothesis across two chapters using empirical paradigms that directly measure infants' existing verb knowledge at this age. In the following section, I outline one additional mechanism that may support infants' verb – and broader word – learning as they develop: infants' own bodily experiences and motoric development.

1.4. Motoric Experiences and Language Acquisition

Dynamic systems and developmental cascade perspectives seek to illuminate how infants' emergent cognitive capacities are the result of "cascading" effects from other cognitive, motoric, social, and perceptual abilities interacting across time (Oakes & Rakison, 2020; Thelen, 2000a, 2000b; Thelen & Smith, 1996). Language acquisition, as has been alluded to in previous sections, is one such example whereby children's ability to produce words unfolds as a consequence of various social and cognitive skills that develop during a child's early life. Indeed, this echoes theories of embodied cognition and cognitive development that suggest conceptual and linguistic knowledge involves a combination of perceptual, sensory, memory, motor, and language systems (Barsalou, 2008, 2010; Glenberg & Gallese, 2012; Piaget, 1952). In support of these viewpoints, a large recent body of literature reports links between children's motor development and their language acquisition (Alcock & Krawczyk, 2010; Clearfield, 2011; Gonzalez et al., 2019; He et al., 2015; Karasik et al., 2011, 2014; Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012, 2015, 2016; Oudgenoeg-Paz & Rivière, 2014; Schneider & Iverson, 2021; Suarez-Rivera et al., 2022; Tamis-Lemonda et al., 2013; Tamis-LeMonda et al., 2019; West et al., 2019, 2022; West & Iverson, 2017, 2021). These studies typically explore these links in two ways: (1) exploring correlations between motor skill onsets and parent-report measures of language development or (2) exploring children's language input in relation to infants' actions and motor abilities. I discuss these literatures in turn.

1.4.1. Motor Skills and Vocabulary Development

Studies using parent-report measures report that both gross and fine motor skills have been associated with concurrent language development and often predict later language outcomes (see Gonzalez et al., 2019, for a review). For example, infants' ability to sit independently (i.e., unaided by a parent) predicts their later receptive vocabulary (Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012). These studies report early sitters acquiring significantly larger productive vocabularies during toddlerhood. That is, sitting offers infants a unique advantage to engage with their immediate environment unencumbered which allows them to independently grasp and explore new objects. Combined with caregiver labelling, novel object exploration helps infants learn new object labels (Yu & Smith, 2012). Similarly, the onset of self-produced locomotion, particularly walking, has been linked to a host of changes that influence infants' interactions with objects and people in their environment. For example, walking infants have been found to have larger vocabularies than age-matched crawling infants (He et al., 2015; Oudgenoeg-Paz et al., 2012, 2016; Walle & Campos, 2014). Changes in infants' day to day experiences as a consequence of walking are thought to foster growth in infants' language and communication. For example, walking infants are afforded visual and hands-free access to distal objects and people, enabling more complex social interactions and the ability to create new opportunities for social communication (Kretch et al., 2014). In contrast, fine motor skills refer to smaller hand actions that require precise coordination such as grasping and object manipulation. Early work in this area found that 4-month-old infants skilled at manipulating objects typically had larger vocabularies at 12 months (Ruddy & Bornstein, 1982). During exploration, infants are able to learn about an object's properties such as shape, colour, textures and weight. In a cross-sectional study, Alcock and Krawczyk (2010) measured fine motor skills and language development in a sample of 21-month-old infants, reporting associations between infants' fine motor skill and language comprehension and production scores.

1.4.2. Infants' Actions Shape Their Language Input

Other studies demonstrate that infants' motoric experiences and language development may be bolstered through increased language input from their caregivers. Typically, these experiments involve video and audio recordings of infants and caregivers interacting in their homes or with little interference in a laboratory set up. For example, West and Iverson (2017) recorded parent-infant dyads in their home longitudinally between 10- and 14-months-old. They found that parents were more likely to engage in labelling if their infant was manipulating an object compared to moments when infants were not holding an object. Similarly, Karasik and colleagues (2014) observed mothers and infants for one hour at home to explore whether infants' walking status (crawling or walking) impacted verbal responses from mothers. Interestingly, the authors found that infants' locomotor status impacted language input, with walking infants receiving more language input and, specifically, verb-based language. Later studies using similar designs also report that infants developing motor skills encourage increased verb and action-based language from their caregivers (Schneider & Iverson, 2022; Tamis-LeMonda et al., 2019; West et al., 2022).

Together, this body of work suggests that infants' language development and vocabulary acquisition may, in part, be supported by their own actions afforded by motor skills onsets that result in more independent exploratory behaviour and increased language input from their caregivers. For verbs, motor gains may serve as an additional important mechanism that helps infants to ascertain the meanings of novel verbs, which I discuss in greater detail during Chapter 4. How might motor skills and actions help infants infer the meanings of verbs? One of the challenges young verb learners face is figuring out which aspects of a complex scene a verb may refer to (Gleitman & Gleitman, 1992). When observing an action in the world, it can be difficult for infants to pinpoint which information is relevant to a new verb given that actions are only briefly perceptually available. Infants' own actions (enabled by increasing motor ability) may create new opportunities for an action to be labelled, increasing verb exposure, as well as helping infants to organise their action concepts and focus in on action commonalities across verb-labelling situations.

1.5. Measuring Word Comprehension in Infants

In this final section of Chapter 1, I overview experimental methods that are used in developmental studies to measure comprehension with infant populations. All of these methods will be applied across this thesis to explore verb comprehension. Broadly, these methods involve parent-report measures of vocabulary, looking time paradigms, and ERP markers of word recognition.

1.5.1. Communicative Development Inventories

Communicative Development Inventories (or CDIs) refer to a collection of parent-report checklists of word items that allow researchers to gain insight into the content, size, and growth of a children's vocabulary development. These measures are used widely across developmental research due to their inexpensive nature and ease to complete in both lab and home settings (e.g., not requiring supervision from experimenter, can be completed on electronic devices) providing broad insight into children's language development that would be difficult to assess in the lab or during home visits. The original CDI, known as the MacArthur-Bates Communicative Development Inventory, was reported by Fenson et al. (1994). This large-scale study collected parent-report data of children's language development from over 1,803 children between the ages of 8- and 30-month-olds. This dataset provided detailed information about children's vocabulary content, vocabulary norms, and the variability of children's word acquisition. Since then, many different adaptations have been created for different languages (see Frank et al., 2017), including a recent adaptation for British English that was normed on a representative population encompassing families from different socioeconomic statuses and inclusive of all British dialects (Alcock, Meints, et al., 2020). Within these measures, caregivers are presented with checklists of early learned words, split into semantic and word class categories (e.g., animal names, action words), and are requested to indicate whether their child understands a word (i.e., comprehends a word but does not say it) or can say it (i.e., can produce the word). Though used widely across language development research, CDIs have been criticised for lacking validity and being prone to parents over-estimating their children's language skills (Tomasello & Mervis, 1994). Yet, empirical studies exploring the accuracy of CDIs show that parents either tend to be conservative (rather than liberal) in their estimations of their infants' vocabulary (Houston-Price et al., 2007) or show relatively accurate estimations of individual items their infant understands (Styles & Plunkett, 2009).

1.5.2. Looking Time Measures

Visual fixations to visual and audio stimuli are widely used as windows into infants' cognitive development. Golinkoff and colleagues (1987) introduced the Intermodal Preferential Looking Paradigm (IPLP) which was the first looking time paradigm that allowed researchers to explore children's word understanding using dynamic, controlled stimuli via video tape (Golinkoff et al., 2013). This task was initially used to explore 16-month-olds' understanding of nouns and verbs. Golinkoff and colleagues (1987) presented infants with videos on two separate television monitors, while infants sat on their parent's lap in front of both screens. Infants were presented with videos of two separate stimuli simultaneously while one of the stimulus items was labelled (e.g., "Where's the boat? Find the boat!"). The authors measured how long infants looked towards each video, as coded online by an experimenter; they found that children often gazed longer at the video that matched the spoken sentences. Since, this paradigm has been used to explore children's understanding of word order, knowledge of syntax, recognition of phonemes, and ability to learn novel words in the lab (see Golinkoff et al., 2013, for a review).

The looking while listening paradigm builds on principles of the IPLP (e.g., simultaneous presentations of stimuli pairs with language, examinations of infants' stimuli fixations) to explore infants' moment to moment language processing (Fernald et al., 2008; Swingley, 2011). Primarily, looking while listening paradigms vary in the way that infants' visual fixations are captured, processed, and analysed. In these tasks, looking behaviour is either captured by camera or by an eye-tracker. Rather than coding infants' fixations to stimuli online during the experiment, looking while listening paradigms code infants' gaze offline. When captured by video, looking behaviour is coded offline with a coder moving through trials frame-by-frame and categorising a fixation as to the target or distractor for each frame. When using an eye-tracker, AOIs are typically created around each stimulus and fixations are labelled as either target or distractor looking for each sample (dependent on the sampling rate of the eye-tracker). This enables the researcher to explore infants' language processing across the span of the trial whilst maintaining the ability to explore children's accuracy (i.e., proportions of trials spent looking at the target). These paradigms have been used to explore a range of linguistic phenomena, such as children's speed of word processing (Fernald et al., 1998) and young infants' existing word knowledge (Bergelson & Swingley, 2012, 2013, 2015; Nomikou et al., 2019).

In recent years, several studies have explored online adaptations of looking time tasks with some of these tasks being conducted synchronously (i.e., in real time with an experimenter in video conferencing software) and others asynchronously (i.e., without an experimenter, hosted on web-based data collection platforms sometimes referred to as unmoderated testing). Collecting data online can be advantageous. For example, online data collection can broaden participant pools to include families that do not live near developmental research sites (typically hosted at universities) and families who cannot participate in research during working hours or have limited free time. That said, online data collection is unlikely to easily resolve issues of participant diversity given that many low-income families or households from non-WEIRD (western, educated, industrialised, rich, and democratic) countries still have reduced internet access (Lourenco & Tasimi, 2020). During the COVID-19 global pandemic, exploring the feasibility of online looking tasks became especially important to ensure that developmental labs around the globe could continue to answer research questions related to cognitive development. Interestingly, many studies that have conducted online replications of their lab-based looking tasks (albeit with adjustments) have reported comparable patterns of results to lab-based studies (e.g., Chuey et al., 2021, 2022; Nelson & Oakes, 2021; Schidelko et al., 2021; Scott et al., 2017; Scott & Schulz, 2017; Smith-Flores et al., 2022).

1.5.3. Event-Related Potentials

Beyond parent-report and looking time measures, ERP markers of language processing have been used to explore infants' word understanding (Friedrich, 2017). ERPs are extracted from time-locked segments within continuous electroencephalogram (EEG) recordings of electrical signals at the scalp and denote activity in response to specific visual, auditory, or motor events (Hoehl & Wahl, 2012). ERP indices offer unique insights into the early lexicon, complementing results from other implicit measures such as looking paradigms. For example, when exploring word processing, ERPs (such as the N400 component) can differentiate between early visual-auditory associations (sometimes known as proto-words) and later word-concept links that incorporate semantic information which is difficult to achieve using looking time measures alone (Friedrich, 2017). Further, ERP measures enable explorations of word understanding that are less impacted by stimuli preference (i.e., looking time measures can be impacted by visual preference; Aslin, 2007).

One particular ERP component that has been used with infants, children, and adults alike to explore language processing is the N400 (Friedrich, 2017; Junge et al., 2021; Kutas & Federmeier, 2011). In a typical N400 task, participants are primed with a meaningful stimulus (e.g., a picture, word, or video) to set the semantic context before being presented with another stimulus (usually a word) that is either congruent or incongruent with the previous stimulus. For example, an infant sees a picture of a dog on the screen before hearing the word "apple" uttered. In contrast to congruent pairs of stimuli, incongruent pairs are associated with a more negatively deflected amplitude that peaks at approximately 400ms post stimulus onset in centro-parietal regions (Kutas & Federmeier, 2011), although this timing and distribution can vary for developmental populations (Junge et al., 2021) and for different types of stimuli. Initially described by Kutas and Hillyard (1980), the N400 component has been used in over 30 studies to explore infants and young children's word comprehension (see Junge et al., 2021, for review).

1.6. Chapter Summary

Across Chapter 1, I presented evidence that verb learning presents as a word learning challenge for children, contrasted against their acquisition of nouns. Theorists suggest this difficulty arises from verbs typically denoting abstract referents and concepts that are perceptually challenging to identify and are "packaged up" differently across languages. Nonetheless, children come to say verbs alongside other words in their earliest lexicons.

Evidently, though verb learning is difficult for early word learners, it is not such an insurmountable challenge that children are unable to resolve. These conflicting set of facts beg the questions as to how and when verbs come to feature in children's early vocabulary. Earlier, I outlined several theories of word learning that have sought to explain *how* children come to learn verbs. The question remains as to *when* children start comprehending verbs. Examinations of linguistic, cognitive, and conceptual developmental literature revealed that many pre-requisites necessary for verb learning (namely word segmentation, event processing, and word-world mapping) have emerged by at least 10-months-old.

Whether infants do in fact understand their first verbs by this age has not been directly tested. In Chapter 2, I describe two looking while listening tasks measuring infants' verb comprehension for several early verbs, using both online and eye-tracking approaches. These studies provide behavioural insight into 10- and 14-month-olds' verb comprehension skills and verb lexicon. I further investigate this in Chapter 3 exploring the N400 ERP, an implicit neural index of word recognition. In the final section of Chapter 1, I described a recent body of literature that has demonstrated clear links between infants' vocabulary development and motoric experiences. Specifically, infants' motor acquisition and own actions in day-to-day life may foster a supportive word learning environment which provide independent exploration moments for infants and language producing opportunities for caregivers. Within this body of literature, several studies reported a particularly important role that infants' motoric experiences play in receiving verb input, within infants' own actions encouraging verb utterances from caregivers. Yet, whether infants' motor skills are related to their verb vocabulary is still unknown. In Chapters 2, I shed light on this question by investigating whether infants' parent-reported motor skills are associated with their performance in looking while listening tasks. Last, in Chapter 4, I describe a study contrasting links between infants' motor development and concurrent verb and noun comprehension, as reported by their parents.

Chapter 2. Exploring Verb Comprehension with Looking While Listening Tasks

2.1. Introduction

Understanding verbs and building a verb lexicon is an important step in children's word learning journey. In Chapter 1, I reviewed literature showing that children find verbs more difficult to learn than nouns, appearing later in their productive vocabulary and far less frequently than noun items (Gentner, 1982; Gentner & Boroditsky, 2001). I also describe how, nonetheless, some verbs do appear early in children's word production and some verbs even are learnt before several concrete nouns (Fenson et al., 1994). Though 40 years of developmental research has made impressive experimental and theoretical contributions to our understanding of how children come to incorporate these verbs into their spoken repertoire (see Hirsh-Pasek & Golinkoff, 2006; Tomasello & Merriman, 1995) and explored the prelinguistic conceptual knowledge that supports later verb learning (e.g., Göksun et al., 2011; Konishi, Pruden, et al., 2016; Konishi, Stahl, et al., 2016; Levine et al., 2018; Pruden et al., 2012, 2013; Pulverman et al., 2013; Song et al., 2016), little is known about when the ability to recognise and comprehend verbs first emerges during infancy.

In the present chapter, I will review research that has begun pinpointing when young infants begin understanding their first words and what types of words are present in their early receptive vocabulary. Here, I describe several studies that have explored when infants begin understanding nouns (Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 1999, 2012) and two studies that have begun providing insight into younger infants' understanding of abstract words and non-nouns (Bergelson & Swingley, 2013; Nomikou et al., 2019). Though not discussed in detail below, it is important to note that several studies have already explored verb comprehension in toddlers and older children using behavioural measures of verb understanding (e.g., having children perform an action, pointing at a target action; Benedict, 1979; Goldfield, 2000; Goldin-Meadow et al., 1976; Huttenlocher et al., 1983; Smith & Sachs, 1990) and looking time paradigms (e.g., Golinkoff et al., 1987; Valleau et al., 2018). For example, Goldin-Meadow et al. (1976) gave 2-year-old children dolls and asked them to perform the action conveyed by the verb on the doll (e.g., "Make the doll *jump*") to measure their verb understanding. In contrast, Golinkoff et al. (1987) presented toddlers with two simultaneous videos of actions completed by a model (e.g., a woman dancing, a woman waving) while hearing audio describing the target action (e.g., "One is *waving*. One is *dancing*. Which one is *waving*?"), reporting that children looked quicker and longer at target items. These studies have provided important insight into toddlers' understanding of verbs. However, aligned with the aims of this thesis, I focus my review of the literature to studies with infants within the first year of life, describing research exploring existing word comprehension using looking time designs. Finally, as noted in Chapter 1, I will also describe studies that report associations between infants' actions and the verb labelling inputs they receive, emphasising why examining links between these domains may broaden our understanding of early verb learning.

2.1.1. Looking While Listening Paradigms

Recent studies have begun charting when and how the early lexicon develops and what words infants first comprehend, measured using looking time paradigms. I briefly outlined several measures of infants' word understanding in Chapter 1, including one common task known as the "looking while listening" paradigm (Fernald et al., 2008; Swingley, 2011). In this task, infants are shown displays of two stimuli, side-by-side, on a screen (e.g., a picture of an apple and a picture of a mouth). Infants are first familiarised with the visual stimuli and their positioning. After, while looking at the same stimuli, infants hear a spoken utterance describing the target item (e.g., "Can you find the apple?" or "Where is the mouth?"). Across trials, infants' fixations to the target stimulus are measured, either by video recording these fixations or recording them with an eye-tracker. Comprehension of word items is measured by ascertaining if infants, on average, look longer to the target item than the distractor after hearing the target labelled. This measurement of word understanding is derived from previous research documenting children's preference to look longer at a target stimulus when named over a familiar distractor stimulus (e.g., Golinkoff et al., 1987). These tasks are typically used to measure infants' knowledge of 6-24 words (Zettersten et al., 2021). Whilst the looking while listening procedure can be used to explore different aspects of children's linguistic processing (e.g., response latencies to spoken stimuli), studies of existing word knowledge typically focus on the proportion of time spent looking to the target item across the trial (e.g., Bergelson & Aslin, 2017; Bergelson & Swingley, 2012, 2013, 2015).

2.1.1.1 Measuring Noun Comprehension

Several studies have applied this methodology to chart which words infants first comprehend and when they start comprehending them. In their seminal study, Bergelson and Swingley (2012) reported that 6- to 9-month-old infants can already understand several concrete nouns. In an eye-tracking looking while listening task, infants saw yoked pairs of images that infants were likely familiar with in their day-to-day life. These items came from two categories: food items (e.g., apple, banana, cookie) and human body-parts (e.g., mouth, hand, foot). They found that infants 6- to 9-months-old looked longer towards the target items for several of the item pairs. These findings were later replicated in a follow up study using video stimuli in place of static images (Bergelson & Swingley, 2015). Two additional studies (Tincoff & Jusczyk, 1999, 2012) have also explored the content of infants' noun lexicon. In the first of these studies, the authors demonstrated that 6-month-old infants associate the words "mommy" or "daddy" with their own parents, but not unfamiliar adults (Tincoff & Jusczyk, 1999). In the second, 6-month-old infants were found to associate videos of adult hands and feet with their labels ("hands", "feet").

2.1.1.2 Measuring Comprehension Beyond Nouns

Two studies have explored word knowledge beyond nouns using looking while listening paradigms within the first year of life (Bergelson & Swingley, 2013; Nomikou et al., 2019). Bergelson & Swingley (2013) tested 6- to 16-month-old infants' comprehension of abstract non-nouns including phrases (e.g., uh-oh), adjectives (e.g., wet), and a small number of verbs (e.g., smile). Within this study, infants were presented with two simultaneous videos of two abstract referents (e.g., "uh-oh" and "bye"), while one of the targets was labelled by their caregiver (e.g., "Look! Uh-oh! Uh-oh!"). Younger infants (6- to 9-months-old) failed to comprehend items in this task, but by 10- to 13-months, infants recognised many non-nouns. These findings reveal that infants' ability to derive the referent of more abstract and complex concepts may be available as early as 10-months-old. However, as this study did not aim to specifically investigate infants' verb knowledge, only a small number of verbs were tested, for which infants' looking performance was mixed. Further, the use of large age ranges (e.g., 10- to 13-months), makes it challenging to determine whether these effects were distributed across the age range or largely driven by older infants in the group. This is especially important to determine as in many recent looking while listening paradigms, infants' preference for target items increases around 12- to 14-months-of-age, which is thought to be a consequence of infants' rapidly growing linguistic, cognitive, and social skills (Bergelson & Swingley, 2012, 2013, 2015, see Bergelson, 2020, for an overview). As such, it is challenging to make broader conclusions about infants' receptive verb lexicon based on these findings.

One additional study presented 9- and 10-month-old infants with pairs of common objects often involved in everyday actions (e.g., a banana to represent eating, a book to represent reading) while their parent uttered a verb related to the target image (e.g., "What can you eat?"; Nomikou et al., 2019). The authors found that 10-month-old, but not 9-month-old, infants readily associated verbs with the target objects. These findings suggest that infants have already begun to associate verbs with event-relevant objects that may be linked with their action concepts. However, this study did not directly test whether infants associate verbs with actions, i.e., by comparing whether infants accurately link verbs with one action exemplar over another. In other looking time studies of verb comprehension with toddlers, children are typically presented with two side-by-side videos of actions rather than static objects (Golinkoff et al., 1987; Valleau et al., 2018). Unlike static objects, videos are thought to serve as more accurate proxies of real-life experiences infants may have with verb labelling events. Specifically, video stimuli require infants to identify the referent of a verb by abstracting components from motion that are relevant to the verb. As such, to accurately assess whether infants recognise that verbs refer to actions, rather than objects typically associated with actions, it is important to present infants with videos or live demonstrations of actions.

In Nomikou and colleagues (2019) study, infants were presented with objects that could be used to perform an action (e.g., a chair for *sitting*) when they heard transitive verbs or objects that were associated with an action (e.g., a bed for *sleeping*) when they heard intransitive verbs. The use of objects, instead of action stimuli, make it challenging to infer whether infants understood that the verbs referred to actions or whether infants incorrectly assigned verbs to the objects themselves. That is, if 10-month-old infants' verb extension is constrained to objects associated with actions rather than the actions themselves, it may suggest that their verb comprehension at this age is not yet linked with event exemplars. Thus, ascertaining when in development infants' can extract event relevant information from dynamic exemplars of actions and associate it with verbs in their existing lexicon, is an important step in understanding infant lexical acquisition. In the current studies, I aimed to address this gap in the literature by directly assessing whether 10-month-old infants already link verbs with actions by measuring their existing verb knowledge.

2.1.2. Associations with Language Development and Infants' Actions

Infants' emergent capabilities (e.g., language skills) represent "cumulative consequences" of cognitive, motoric, social, and perceptual interactions that have occurred across an infant's life (Oakes & Rakison, 2020, p. 101). That is, infants' word learning does not occur in isolation. Rather, word learning occurs as the result of many gradual changes in infants' perceptual skills (e.g., increasing visual acuity, phoneme perception), social abilities (e.g., following gaze to referents), cognitive mechanisms (e.g., improving recognition memory), and motor skills (e.g., object manipulation;Oakes & Rakison, 2020; Thelen, 2000b, 2000a; Thelen & Smith, 1996). As discussed in Chapter 1, much research has documented how changes in infants' language skills and language input received from their caregivers can be stimulated by newly acquired motor skills and increasing experience executing actions (Alcock & Krawczyk, 2010; Clearfield, 2011; Gonzalez et al., 2019; He et al., 2015; Karasik et al., 2011, 2014; Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012, 2015, 2016; Oudgenoeg-Paz & Rivière, 2014; Schneider & Iverson, 2021; Suarez-Rivera et al., 2022; Tamis-Lemonda et al., 2013; Tamis-LeMonda et al., 2019; West et al., 2019, 2022; West & Iverson, 2017, 2021). Aligned with Piagetian (1952) perspectives of cognitive development, this literature demonstrates that infants acquire conceptual and linguistic knowledge within the context of their sensorimotor experiences.

2.1.2.1 Verb Input and the Active Infant

Recently, researchers have turned their attention to understanding the potential cascading benefits infants' motoric experiences may have on verb labelling input from caregivers and their subsequent verb learning. So far, a small number of studies have examined the verb input infants receive during their real time actions at home. Karasik et al. (2014) focused on comparisons of crawling compared to walking infants to explore whether infants' motor development impacted linguistic input received from infants' mothers. Mothers of walking infants were much more likely to produce verb tokens in response to infants' stationary bids with objects (i.e., offering an object from a static position, often while sitting) than those of crawling infants. Further, the researchers reported that when infants engaged in moving bids (i.e., actively moving towards their mother while offering an object) then mothers were equally likely to offer verbs in response regardless of crawling or walking status. Similarly, Schneider and Iverson (2022) also found that caregivers often pair action verb naming events alongside bouts of their infant walking independently, but not with bouts of crawling or supported walking.

Tamis-LeMonda et al. (2019) collected video recordings of 40 mother-infant dyads at home during everyday activities. Mothers' language input and the types of activities engaged in were later transcribed and coded. Specifically, the authors transcribed mothers' use of concrete nouns and action verbs within the activity context in which they were produced. Mothers' verb usage was coordinated with the type of activity (e.g., eating/cooking related verbs produced during feeding time, washing/dressing related verbs produced during grooming activities). Interestingly, mothers were most likely to use gross motor verbs (e.g., walking, crawling) when infants were "transitioning" from one activity to another by walking or crawling to their new task. Another study using home observations with mother-infant dyads showed that mothers describe infants' actions often, on average 80 times per hour (West et al., 2022). These verb utterances generally aligned with infants' moment-to-moment actions by congruently describing the types of actions witnessed (e.g., when infants were engaged in a manual action with their hands, mothers uttered a manual action verb). Further, older infants with more refined and diverse motor capabilities (and likely language skills) in turn received a greater number of action labelling events and heard a more diverse range of verbs.

Together, these findings suggest that infants' own actions may shape their verb learning by increasingly creating opportunities for caregivers to label verbs. These findings raise an important question. Namely, whether infants' increasing motor skills and action capabilities are, in fact, associated with their verb learning. For noun learning, studies suggest that infants' acquisition of novel nouns is facilitated by co-occurrence of object labelling by caregivers and infants' object manipulation (Pereira et al., 2014; Yu & Smith, 2012). Studies exploring early verb acquisition report that many of children's earliest verbs typically describe bodily actions that children have experience performing early in life, which may suggest children use their own actions to infer the meanings of novel verbs (Maouene et al., 2008, 2011). Nonetheless, whether infants developing motor skills are associated with the verbs infants understand is unknown.

2.2. The Current Studies

In the present research, I aimed to investigate (1) whether infants have already begun understanding verbs by at least 10-months-old, (2) what verbs infants comprehend at this age, and (3) whether infants' verb knowledge is associated with their motor abilities. To do this, I conducted two studies using looking-while-listening paradigms and collected parent-report measures of motor development and action experiences. Study 1 was conducted online with 10- and 14-month-old infants and used manual coding to classify infants' looking behaviours. Study 2 was conducted in the lab with 10-month-olds only and recorded infants' looking behaviour with an eye-tracker. These two ages were tested as they likely represent different important stages in infants' verb learning capabilities. Ten-month-olds are able to identify and categorise actions (Baldwin et al., 2001; Pruden et al., 2012, 2013; Pulverman et al., 2008, 2013; Sharon & Wynn, 1998; Woodward, 1998; Woodward et al., 2009; Wynn, 1996), can segment some words from speech (e.g., Jusczyk, Hohne, et al., 1999; Jusczyk, Houston, et al., 1999; Jusczyk & Aslin, 1995; Saffran et al., 1996; Werker & Hensch, 2015) and have been found to map some non-nouns to their referents (Bergelson & Swingley, 2013). By 14-month-olds, infants have begun saying their first words (Fenson et al., 1994), better comprehend different types of words (Bergelson, 2020; Bergelson & Swingley, 2012, 2013), can segment verbs from speech (Nazzi et al., 2005), and exhibit more sophisticated event processing capabilities (Pruden et al., 2012). Thus, 14-month-olds make for an interesting group for 10-month-olds to be compared against. Further, as I expected that infants of this older age would likely already understand verbs, this group also served as a form of manipulation check during Study 1 as no studies collecting synchronous looking data online had been published at the time of data collection. Across these studies, several hypotheses were tested:

Hypothesis 1: By 10-months-old, infants exhibit emerging event processing skills, word comprehension capabilities, and the ability to understand some non-nouns. I predicted that 10-month-olds would understand several verbs in the looking while listening paradigm, with infants looking longer at the target item for several verb pairs. I expected that, on average and across verb items, 10-month-olds would look longer at the target item.

Hypothesis 2: Fourteen-month-olds are reported to experience a "word comprehension boost", exhibiting increased target looking in word learning tasks. I predicted that 14-month-old infants would looking longer at the target item for most verb pairs. I also expected that 14-month-olds looking performance would be greater than that of 10-month-olds, showing a stronger preference for target items (Bergelson, 2020).

Hypothesis 3: Infants' developing motor skills provide novel opportunities for verb learning to occur, with caregivers congruently labelling actions that infants produce. I predicted that infants' motoric abilities would be associated with their verb comprehension skills. I explored this in several ways: (1) by investigating correlations between infants' target looking and motor development and (2) by investigating correlations between infants' target looking and types of motor development (i.e., manual/fine motor skills, whole-body/gross motor skills) as measured by the Early Motor Questionnaire (Libertus & Landa, 2013). Further, (3) I explored whether infants' target looking was associated with their communicative action and gesture capabilities as measured by the UK-CDI: Actions and Gestures (Alcock, Meints, et al., 2020). As previous research shows children's first verbs are strongly associated with body parts infants' use to do actions, I also expected that there would be links between the verbs infants understand and the actions they can do. Therefore, (4) I examined whether infants' target looking was associated with the number of these actions infants could perform. Finally, as walking ability seems to promote most action-naming events from parents, (5) I explored whether overall looking performance is different between infants not yet able to walk, infants who can walk with some support, and independent walkers.

Hypotheses 1 and 3 were tested across both studies. As I only collected data from 14-month-olds in Study 1, hypothesis 2 (concerning 14-month-olds looking performance) was tested only in Study 1. Additional exploratory analyses were conducted to explore if there were any links between infants' target looking and their language skills as reported by their caregivers via the UK-CDI. I also conducted an exploratory integrative analysis which combined 10-month-olds looking behaviour across Study 1 and Study 2, in line with current suggestions for increasing power across studies exploring the same research question (Lakens & Etz, 2017).

2.3. Study 1: Measuring Verb Comprehension Online

Study 1 examined 10- and 14-month-olds' comprehension with a set of 10 early verbs with looking while listening paradigm (Fernald et al., 2008; Swingley, 2011). Specifically, I tested infants' comprehension of verbs that are reported to be some of the earliest ones comprehended and produced by infants and toddlers (see **2.4.3.1 Stimuli Selection** for details). This study was conducted online using Zoom (Zoom Video Communications, 2022) video conferencing software. Collecting looking behaviour data online with developmental populations has been gaining increasing popularity since the introduction of the "Lookit" platform. Lookit is a platform that allows families to asynchronously take part in behavioural studies online by collecting looking behaviour via webcams (Scott et al., 2017; Scott & Schulz, 2017). During the COVID-19 pandemic in March 2020, developmental labs across the world were restricted from collecting in-lab data for several months, and many labs rapidly began adapting their in-lab methodologies for online replication (e.g., Bacon et al., 2021; Kominsky et al., 2021; Lapidow et al., 2021; Lourenco & Tasimi, 2020; Nelson & Oakes, 2021; Schidelko et al., 2021; Zaadnoordijk et al., 2021). Zoom software, like other video conferencing software, enables users to see and hear each other via computer microphones, speakers, and webcams. Additionally, Zoom allows users to share visual and audio content from one device to another and can video record sessions, capturing webcam/microphones feeds and shared content. Several labs using Zoom, or other online platforms, to explore infant and children's word comprehension or looking behaviour have found comparable results to in lab studies (Lapidow et al., 2021; Nelson & Oakes, 2021; Smith-Flores et al., 2022). Here, Study 1 was conducted during the COVID-19 pandemic and continued to collect data through 2022. In Study 2, I adapted Study 1's design in a laboratory setting with an eye-tracker to ensure that both methods result in similar patterns of looking behaviour (see **2.9.4 Integrative Analyses** for details).

During this study, over a Zoom videocall, infants were presented with yoked pairs of videos of action exemplars, with one video showing the target item and the other acting as a distractor item. Across the task, infants heard verbs that described the target action and infants' fixations to the target and distractor were recorded via their caregiver's webcam.

2.4. Method

2.4.1. Ethical Approval

This study is associated with ethics application number EC.19.03.12.5595GRA3 and was approved by the Cardiff University School of Psychology Ethics Committee.

2.4.2. Participants

In total, 25 10-month-olds (13 female, $M = 10.1$ months, $SD = 0.32$, *range* = 9.61-10.6 months) and 21 14-month-olds (7 female, $M = 14.0$ months, $SD = 0.40$, *range* = 13.4-14.9 months) were tested. To ascertain the study sample size, I did not conduct a formal power analysis, but rather based the sample size targets on recent recommendations for infant looking-time designs (Oakes, 2017). This sample size is comparable to previous looking while listening studies with infants (e.g., Bergelson & Swingley, 2015; Swingley, 2005). Families were recruited via social media post/adverts and the Tiny to Tots Research Panel, a database of families based in Cardiff and South Wales interested in developmental research. Six infants from this sample were excluded from analysis due to fussiness ($n = 2$), technical issues ($n = 2$), poor video quality ($n = 1$), and due to being born prematurely ($n = 1$).

The final sample included 22 10-month-olds (10 female, *M* = 10.1 months, *SD* = 0.33, *range* = 9.61-10.6 months) and 18 14-month-olds (5 female, *M* = 14.0 months, *SD* = 0.42, *range* = 13.4-14.9 months). All infants were monolingual, English-hearing infants. Infants were classified as monolingual if they were exposed to 75% or more English at home and/or in care settings (e.g., nursery), a common threshold for establishing monolingualism in infant word comprehension studies (Bergelson & Swingley, 2012, 2013, 2015). All infants were born full term (i.e., 37 weeks or later) and had a typical birth weight (i.e., 5lb 9oz/2.52kg to 9lb 14oz/4.48kg)[1]. All infants were reported as typically developing and did not experience any developmental delays with vision, hearing, communication, or motor development. Thirty families were living in Wales and eight families were living in England at the time of testing. All infants were reported to be White-British (*n* = 39) or White-European (*n* = 1). Two families did not provide demographic information.

Families were predominately middle class, with an average income of £72,500 (*SD* = £33,849, *range* = £24,000-£150,000) before taxes. All participating parents were women, and the average age was 34 years (*SD* = 3.76 years, *range* = 25-42 years). Two parents (5.3%) were educated up to GCSE (i.e., high school) level, 16 (42.1%) had Bachelor's degrees, 16 (42.1%) had Master's degrees, and three (7.9%) had an M.D., P.h.D., or equivalent.

Caregivers provided written, informed consent prior to the study via a REDCap (Harris et al., 2009, 2019) consent form and provided recorded verbal consent during the experimental session. All families received a £5 voucher for beginning a study (i.e., joining the online video call) regardless of infant compliance, study completion, technical difficulties, or study withdrawal.

2.4.3. Materials

2.4.3.1 Stimuli Selection

In selecting and designing verb/action stimuli, my goal was to include verb items that infants at both ages (i.e., 10- and 14-months-old) would likely comprehend. One method that can be used to estimate words that children comprehend during early development is by asking parents to report which words they believe their children can understand or say at different time points. Instruments such as the MacArthur-Bates Communicative Development

[1] Two infants were reported to have lower than typical weight. These infants were related twins and had a birth weight that is considered healthy for twins and, thus, were considered as having typical birth weights and were included in the final sample. These infants were born full term.

Inventories (M-CDI, Fenson et al., 1994) and British-English adapted versions (Alcock, Meints, et al., 2020; Hamilton et al., 2000) are used widely to measure children's early vocabulary development by using large checklists of items that children may understand or say. To date, a large, open-source database with CDI contributions from many studies and labs for multiple languages is freely available for exploring vocabulary norms (Frank et al., 2017).

However, most CDIs include few verb items that describe the gestures and actions that children first learn to produce (e.g., clap, crawl, wave). Measures such as the M-CDI (Fenson et al., 1994) and UK-CDI (Alcock, Meints, et al., 2020) do include an *Actions and Gestures* section to measure children's ability to perform several gestures and actions. Nonetheless, many of the equivalent verb items do not appear in the word items check list. For the current studies, this may be problematic when deriving verb comprehension items from CDI measures as during development infants learn new words within the context of their early bodily experiences (Schroer & Yu, 2022; Yu & Smith, 2012) and may learn the names for actions they can produce first. As discussed above, caregivers' infant-directed verbs tend to be temporally synchronous and congruent with actions infants produce in real-time (Nomikou et al., 2017; West et al., 2022). Prior research also suggests that children may exploit their own experiences with actions to ascertain verb meanings. Many of the early verbs produced by children are associated with the body parts children are proficient at using to self-produce corresponding actions (Maouene et al., 2008, 2011). Similarly, when learning a new verb, children also benefit from experience observing or producing a congruent action or gesture (Aussems et al., 2021; Aussems & Kita, 2020; Gampe et al., 2016; Mumford & Kita, 2014; Wakefield et al., 2018). These studies provide indications that children may first acquire verbs that describe the actions they have the most experience with.

For that reason, to select items for the current study, I invited parents of infants to take part in an online survey including an adapted Oxford Communicative Development Inventory[2] (Hamilton et al., 2000) that included additional verb items. I describe the design and full sample for this study in detail in Chapter 4 (see **4.3 Method**). I added an additional 19 verb items (e.g., clap, wave) to the Oxford-CDI that represent some of the earliest actions, gestures, and motoric skills infants learn to perform. I derived these verbs from actions,

[2] Since conducting this survey, a recent CDI for UK infants has been published (see **Method** section; Alcock, Meints, et al., 2020)) that is more representative of British infants in terms of social economic status and dialects. Unfortunately, this measure was not available at the time of conducting the initial survey. In all later experimental studies featured in this thesis, the UK-CDI was used rather than the Oxford-CDI.

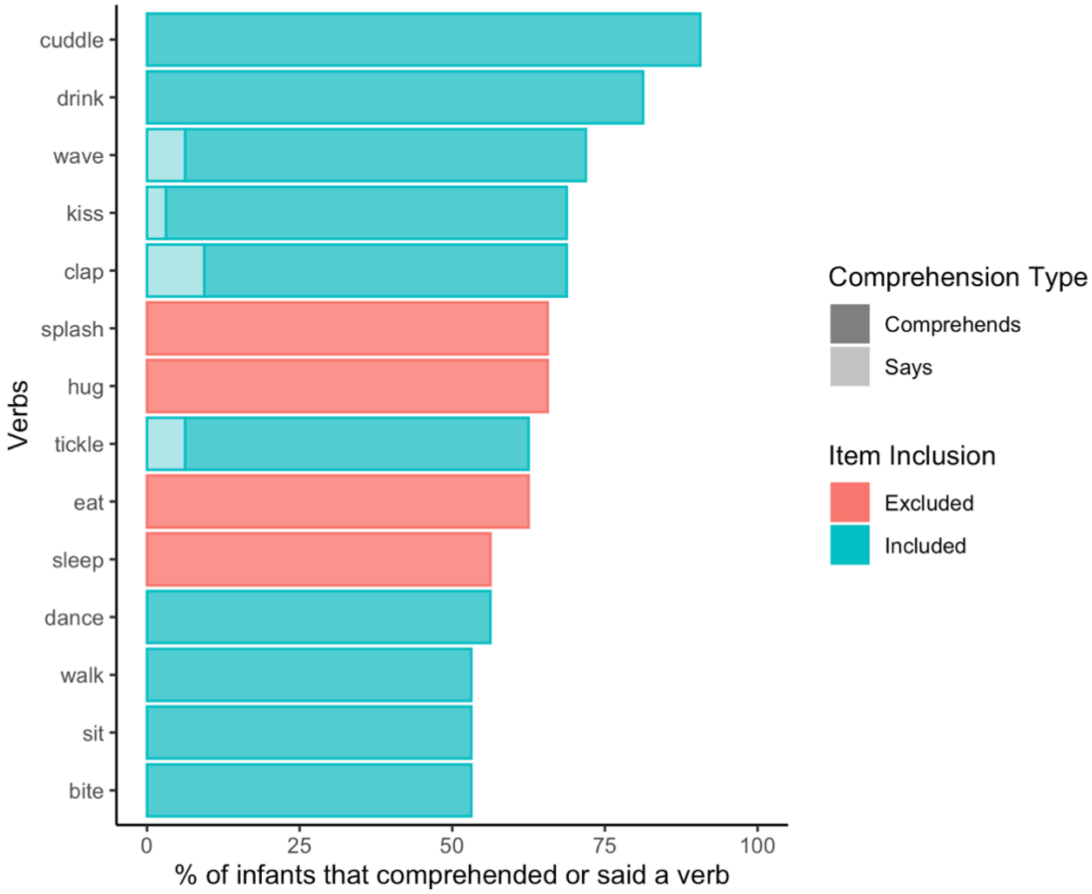
gestures, and motor skills described in the Early Motor Questionnaire (EMQ; Libertus & Landa, 2013) and MacArthur-Bates Actions and Gestures (Fenson et al., 1994) which measure actions and motor skills children can produce in the first years of life. In total, 86 verb items featured in the measure, out of a total of 568 word items. A list of the additional verb items and where in the EMQ and M-CDI they were selected from can be found in **Appendix A**.

While data from the full sample are reported in Chapter 4, to select verb items I restricted my analysis to infants between 9- and 15-months-old to align with the age of infants taking part in the looking while listening tasks. This sample included 32 infants (20 female, M = 12.1 months, SD = 1.6, *range* = 9-14.95 months) compared to the 83 participants included in Chapter 4. I shortlisted items that were reported as understood and/or spoken by more than 50% of 9- to 15-month-olds in the sample. Items were excluded if they (1) were too abstract or challenging to demonstrate in a video (e.g., splash), (2) visually or semantically similar to other shortlisted items (e.g., hug removed due to similarity with cuddle). *Eat* was also removed due to potentially problematic overlaps with this word being used for both breast-feeding and eating food during early infancy (Nomikou et al., 2019). The shortlisted items, displaying final and excluded items, and the percentage of infants in the sample reported to comprehend/say the item can be seen in **Figure 2.1**. In total, 10 items were selected; bite, clap, cuddle, dance, drink, kiss, sit, tickle, walk, wave.

In looking-while-listening tasks, items are typically arranged into yoked pairs, e.g., *bite* and *clap* consistently paired together across the task, with each item alternately being the named stimulus. This reduces the likelihood that preference for a particular stimulus (e.g., for the bite over the clap video) results in increased performance in trials where that item is the target (Swingley, 2011). Accordingly, items were organised into five yoked pairs: bite-clap, cuddle-dance, drink-walk, kiss-sit, tickle-wave. Pairs were selected to ensure that items were semantically dissimilar (Bergelson & Aslin, 2017), phonetically dissimilar, started with different letters, displayed similar degrees of movement, and contained both a transitive and intransitive verb to control for the presence of an object involved in the action. The data and analysis script used to select the final verb items are publicly available at https://osf.io/mbn94/?view_only=8f9e3fd67e3d4fc5a7eb562626229b12.

Figure 2.1

Shortlisted verb stimuli and percentage of infants reported to understand a given verb



Note: This figure displays the 14 verb items that more than 50% of caregivers reported their infant able to comprehend or say out of a possible 86 verb items. Dark subsections show the percentage of infants reported to comprehend an item. Light subsections show the percentage of infants reported to say an item. Blue bars were included in the final stimuli selection. Pink bars show excluded items.

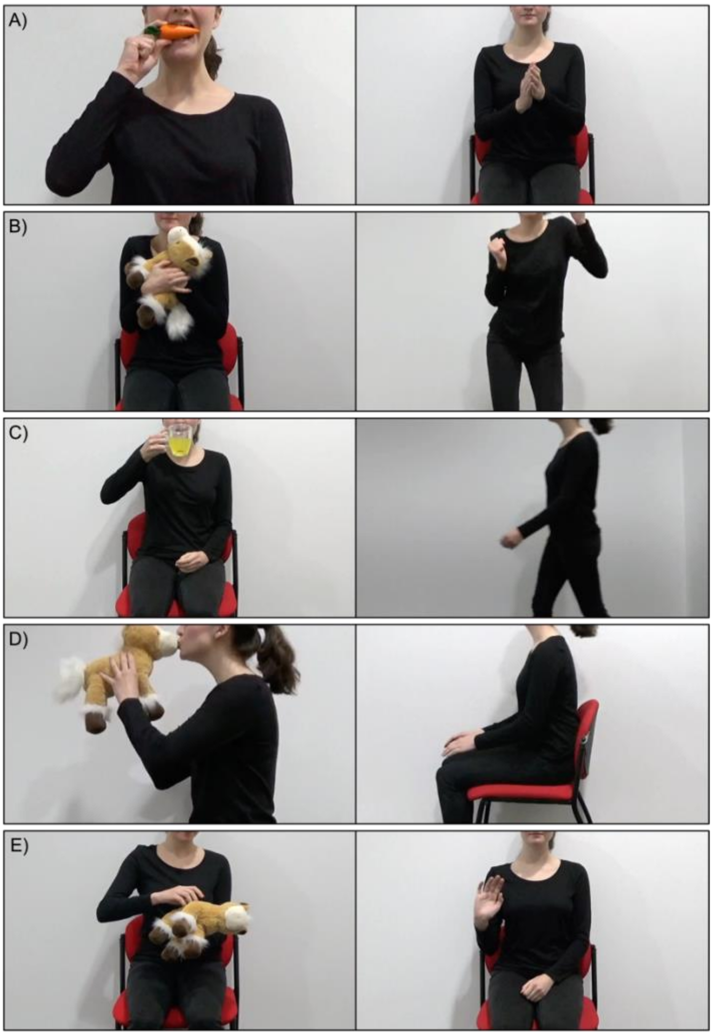
2.4.3.2 Stimuli

A set of 10 videos and 10 spoken verb labels were recorded. Stimulus videos depicted a white female model in front of a plain white background performing simple actions associated with the selected verb items. The model wore plain black clothes and pulled-back hair. The model's eyes were not visible to reduce infant attentional bias (Haith et al., 1977). Videos were 4000ms in length and edited in iMovie and FFMPEG command line software[3]. **Figure 2.2** shows a still image of each action performed. As the video stimuli were presented

[3] Due to a technical error with editing software, videos for the familiarisation trials were shorter than those during the test trials at 3850ms for the online study (Study 1). For all videos, this did not impact recognisability of the action as the goal of the action was evident at ~2000ms.

full-screen on caregiver's computer screen, the dimensions of video stimuli were variable across participants. However, caregivers were required to have a computer that was at least 13" and, thus, video stimuli had minimum dimensions of 120mm(W) x 68mm(H). Audio were spoken in infant-directed English by a native female speaker from the UK. The audio stimuli were trimmed, and noise reduced using Audacity® software (Audacity Team, 2019) and normalised to 70dB using Praat software (Version 6.0.48; Boersma & Weenink, 2019). The spoken verbs ranged from 660ms to 1030ms in length. Stimulus videos and audio are publicly available at https://osf.io/mbn94/?view_only=8f9e3fd67e3d4fc5a7eb562626229b12. Attention getter videos were adapted from Schlegelmilch and Wertz's (2019) calibration target stimuli.

Figure 2.1
Still frames from video stimuli



Note: A still frame from each stimulus, organised into yoked pairs. A) bite-clap, B) cuddle-dance, C) drink-walk, D) kiss-sit, and E) tickle-wave.

2.4.3.3 Parent-Report Measures

Caregivers completed three questionnaires via REDCap (Harris et al., 2009, 2019), after the experimental session. Personal links were emailed which directed them to the questionnaires and requested measures to be completed within one week to provide the clearest overview of their infant's language and motor development at the time of the experiment. Email reminders were sent once a day for one week. At the end of each questionnaire, caregivers were provided with an open comments box to provide any additional information about their infant, their responses, any difficulty completing the questionnaire, or any feedback they had about the questionnaire measure. Caregivers were informed that they were able to skip any questionnaire that they did not feel comfortable completing but were made aware that the software would automatically prompt them to provide a response.

2.4.3.3.1 Family and Demographic Questionnaire. Caregivers were asked questions regarding their infant (e.g., sex, ethnicity) and their infant's health and development (e.g., birth weight), family socio-economic status (e.g., caregiver education level, income), and family demographics (e.g., ethnicity, caregiver gender).

2.4.3.3.2 UK-Communicative Development Inventory. The UK-CDI (Alcock, Meints, et al., 2020) is a parent-report checklist of words and gestures that children may understand and use and can be used with children aged between 8 and 18 months. This measure was normed on a representative UK sample in terms of socioeconomic status, ethnicity, region, and dialect. For words, caregivers are asked whether their child understands or produces a word, yielding scores for both overall word production and comprehension. For gestures, caregivers are asked how often their child uses a gesture (*not yet, sometimes, often*) and if they can do certain actions (*yes*, *no*). Additional verb items that featured in the looking task were added to the measure, with permission from the UK-CDI authors[4]. Additional action/gesture items were also added to the measure that measured whether children could complete the actions associated with the verbs in the task. A list of the additional action/gesture items can be found in **Appendix B**.

Word comprehension scores are computed by summing the total number of words understood and the total number of words said, and production scores equal the total number of words said (total possible score of 395 for both comprehension and production). Gesture

[4] Note that these items do not feature in the CDI scores described. The additional verbs added were only used to separately compute how many of the verbs from the task parents report their infant to understand.

scores are computed by 0.5 x total of gestures + total number of actions (total possible score of 63).

2.4.3.3.3 Early Motor Questionnaire. The Early Motor Questionnaire (EMQ; Libertus & Landa, 2013).is a parent-report measure of early motor skills and behaviours. The EMQ is divided into three sections exploring gross motor skills, fine motor skills and perception action abilities. Caregivers use a 5-point scale, that ranges from -2 to +2, indicating how certain they are that they have witnessed their child producing a motor skill. A rating of -2 is given if a parent is certain that their child has not or cannot complete a motor skill and +2 if they can remember a specific instance when their child produced a motor skill. Caregivers are encouraged to use the 0 rating sparingly, which indicates uncertainty. Scores are calculated by summing together all scores and can range from -256 to +256. Parents' responses on the EMQ are reported as comparable to other standardised and experimenter-administered motor skill measures (Libertus & Landa, 2013).

2.4.4. Procedure

Families took part in the experimental session from their homes and joined via a video call in Zoom (Zoom Video Communications, 2022) video-conferencing software. To participate, caregivers were required to have access to a computer or laptop with a 13" or larger screen. The device was required to have (1) a functioning webcam, (2) functioning speakers, and (3) the ability to host the desktop version of Zoom video software.

To increase experimental control, I attempted to standardise family's at-home setup in several ways. First, participant appointments were arranged around infant and family schedules. To ensure infants were alert and comfortable during the session, I scheduled appointments shortly after infant naps and feed/snack times. When possible, appointments were also scheduled when the home environment was quieter (e.g., siblings at nursery/school). Second, prior to their experimental session, caregivers were sent a preparation manual with guidance on how to position their infant and device during the task (i.e., on caregiver's lap in front of device *or* in a highchair in front of device) and how to reduce distractions (e.g., placing pets in another room). Finally, during the call, I confirmed with parents that no visual/audio distractors were nearby, doors/windows were closed, device notifications were turned off, and that infants were unable to reach the device with their hands or feet.

Prior to their online appointment, caregivers were emailed a URL link to their Zoom appointment. Once the experimenter joined the videocall, the Zoom session began video recording the session. After joining the videocall, the procedure was explained, and caregivers provided their verbal consent[5]. Infants either sat on their caregiver's lap or in a highchair with their caregiver sat nearby (e.g., to the side or behind their infant), in front of the device. Caregivers were instructed to remain neutral throughout the experiment and asked not to point at the screen or speak during the task, unless taking a break with their infant[6]. Prior to starting the task, the experimenter played an example audio file to ensure that caregivers had suitable volume levels set on their device. The experimenter also ensured that the infant was seated in front of the webcam so that their eyes and face were clearly visible.

The stimuli were presented to the infant via a Youtube playlist[7]. Using remote control of the caregiver's screen, the experimenter was able to ensure that the stimuli were presented full-screen and was able to control presentation of video stimuli (e.g., pause if the infant was fussy, move onto the next trial). First, a 5-point calibration was completed where infants saw a spinning ball in each of the four corners of the screen before being seen in the centre of the screen. This supported later video coding by aiding coders in differentiating between on- and off-screen looks. Each trial began with an attention getter that directed infants' gaze to the centre of the screen. First, during familiarisation, infants were presented with a yoked pair of videos, side-by-side, accompanied by music. This familiarised infants with the video stimuli and their location during that trial. During test trials, directly after familiarisation, infants saw the same videos again accompanied by a spoken label describing the target action. The spoken label onset began with the video onset. The label consisted solely of a spoken verb, the verb duration ranging from 660ms to 1030ms. Across the task, each pair of videos was presented four times, with each item acting as the target twice and as the distractor twice. The position of the target video was counterbalanced across trials. This resulted in 20 test trials in total. Infants were randomly assigned to one of two pseudorandomised orders. Both pseudorandomised orders equally distributed verb pairs across the first and second half of the experiment and ensured that verb pairs did not repeat in consecutive trials. **Figure 2.3** shows

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[5] To record verbal consent, caregivers were asked to read the follow sentences that were displayed over Zoom and say them out loud if they agreed to them "*I have read and understood the information sheet. I am this child's legal guardian and agree for them to take part in this study. I understand that we are being video recorded. I know that we can stop at any time without penalty*."

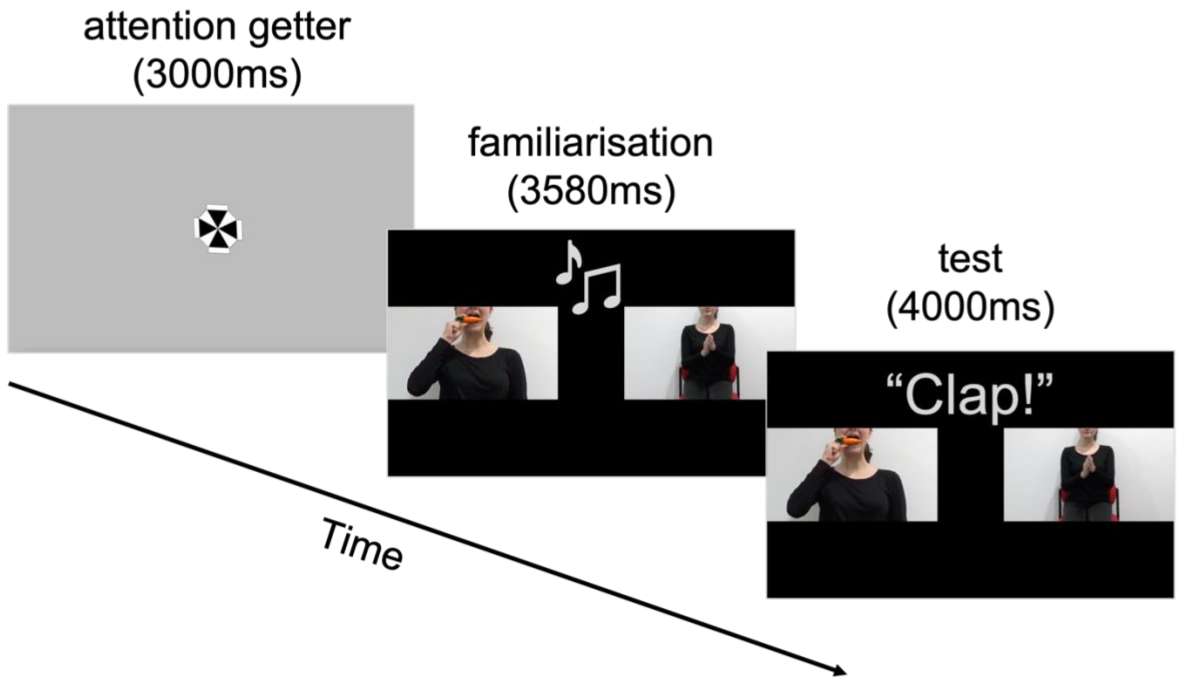
[6] Recent studies have reported that caregivers' familiarity with stimuli during looking-time studies can influence infants' looking behaviour (Alcock, Watts, et al., 2020). Typically, in lab studies have attempted to address this by restricting caregivers' from seeing or hearing stimuli. Due to the online and at-home nature of this study, I refrained from asking caregivers to engage in these behaviours as infants' safety and needs could only be effectively monitored by the caregiver at home.

[7] An example playlist can be publicly viewed at https://youtube.com/playlist?list=PLJmfoAKxNJXaHxgiHze0T9N2lfmbrw8rt

the task timeline. Testing continued until all trials had been completed or until infants' attention could no longer be maintained. The task lasted approximately 5 minutes, with the whole session lasting approximately 25 minutes.

At the end of the task, caregivers confirmed that the stimuli displayed and played correctly. After the session, caregivers were sent a URL link to complete the demographic questionnaire, UK-CDI, and EMQ.

Figure 2.2
Trial timeline for the online looking-while-listening task



2.4.5. Video Coding

Video coding of infants' looking behaviour was completed using ELAN software (Lausberg & Sloetjes, 2009) and followed the "looking-while-listening" video coding procedures (Fernald et al., 2008; Swingley, 2011). Video coding was completed in two stages: pre-screening and gaze coding. I pre-screened and coded all infant sessions. A second reliability coder gaze coded a subset of the dataset. The pre-screening involved seeing the stimuli presented during testing and listening to the audio from the session to confirm the onset of the verb stimuli/trial. The pre-screening process also involved examining footage of the infant to assess any possible interference or issues with internet connection. As I acted as both the pre-screener and primary coder, I ensured to have a break of one week between pre-screening and gaze coding to reduce bias. During gaze coding, the primary and secondary coder only saw footage of the infant's face and completed the coding in silence.

2.4.5.1 Pre-Screening

In this first stage, trial times and boundaries (i.e., the onset and offset of trials) were identified to guide later gaze coding. Video recordings were initially pre-screened to identify trials that should be excluded from analysis due to the infant's looking responses likely being influenced by factors beyond the stimuli (e.g., external sound, caregiver interference) or where accuracy of gaze coding may be impacted due to technical issues (e.g., video signal froze, image quality temporarily dropped due to poor internet connection). On average, 1.56 test trials (*SD* = 1.73, *range* = 0-6), per infant, were excluded for these reasons.

2.4.5.2 Gaze Coding

In the second stage, infants' eye movements were manually coded frame-by-frame (frame length = 40ms). For both trial types (i.e., familiarisation, test) coding began with the onset of the video until the end of that trial (familiarisation = 3850ms, test = 4000ms). Coding segments classified infants' looking as *left* (at the left video), *right* (at the right video), *centre* (between the videos), *off-screen* (when the infant looked anywhere away from the screen) or as *un-codable* (coding was not possible for reasons such as long blinks, eyes covered, or video being blurry). Coders were encouraged to use the *centre* code sparingly as infant fixations were unlikely to be directed to the black column between video stimuli during trials. Only fixations towards a stimulus (i.e., *left* or *right* look) were included in analyses. Looking segments ended on the last frame where a specific looking behaviour (e.g., *left* look) was visible. For transitions between looking directions, coders could toggle between frames or compare against the calibration period to increase accuracy in their decisions. As knowledge of the verbal stimuli can introduce bias when video coding (Fernald et al., 2008), neutral labels (e.g., *familiarisation_trial1, test_trial15*) were given to trial boundaries created during the first stage of pre-screening and video coding was completed without audio. Both the primary and reliability coder were blind to the counterbalance order and target position during coding.

To measure inter-rater reliability, an independent postgraduate observer coded 12 infants' (6 10-month-olds, 6 14-month-olds) looking behaviour. Prior to coding a subsection of the final dataset, the reliability coder trained on two example sessions. Aligned with looking-while-listening protocols (Fernald et al., 2008), the reliability coder trained on the example sessions until the majority of *left* and *right* timings for each trial were within 1 frame (i.e., 40ms) of each other, when compared against the primary coder. The independent rater was blind to the trial order and target position. Intraclass correlations were conducted on the proportions of target looking across all trials between the two raters. Intraclass correlations revealed a coefficient of .93, indicating excellent agreement between the raters[8].

2.4.6. Data Processing

To investigate infants' verb comprehension, I explored whether infants looked longer to the target stimulus after hearing it named, across test trials. To examine this, I applied a widely used index of word comprehension during early development: the proportion of time looking at the target (e.g., Fernald et al., 2008; Goldfield et al., 2016; Swingley, 2011; Tincoff & Jusczyk, 1999). This proportion was calculated by summing up the amount of time looking the target, divided by the total amount of time looking at the target and distractor. Using proportional, compared to absolute, looking times reduces bias introduced by infants who look longer overall across the task.

2.4.6.1 Bias Correction

Looking while listening studies often also apply baseline corrections to infants' target looking to correct for stimulus preference. These corrections result in difference scores that aim to increase the likelihood that infants' looks to a target item are the result of mapping a word onto the stimulus rather than due to a visual preference. This is typically done in one of two ways. One correction, hereby referred to as a *pre-label correction*, involves taking the proportion of time looking at a stimulus during a test trial, minus the proportion of time looking at the same stimulus either during a familiarisation trial or a period prior to the target word being spoken (e.g., Bergelson & Aslin, 2017; Nomikou et al., 2019). Pre-label corrections create a score for each word item. The other, hereby referred to as a *post-label correction*, involves taking the proportion of time looking at a stimulus when it was the target, minus the proportion of time looking at the same stimulus when it was a distractor (e.g., Bergelson & Swingley, 2012, 2013, 2015). This computation creates scores per verb

[8] Intraclass correlations were also assessed on raw looking times towards the target, also revealing excellent agreement with a coefficient of .92. Intraclass correlations were conducted using the *ICC*() function from the *psych* package (Revelle, 2022).

pair, rather than by individual items[9]. Both corrections result in scores between -1 and 1, with scores greater than zero indicating fixating longer on the target stimulus. Both computations aim to reduce the impact of visual preference on looking times, but the post-labelling correction has been used more widely in studies measuring infants' existing word knowledge (Bergelson & Swingley, 2012, 2013, 2015). As such, the post-labelling correction is applied across this chapter. However, equivalent analyses, largely reporting similar patterns of results, were conducted by applying the pre-labelling correction which can be seen in **Appendix C**.

2.4.6.2 Window of Interest

During test trials, analyses were limited to infants' looking responses during a window of interest that ranged from 367ms after the onset of the spoken verb stimuli (e.g., after the beginning of "clap!") until the end of the trial. This window is frequently used in looking while listening tasks measuring existing word knowledge with infant participants (Bergelson & Swingley, 2012, 2013, 2015; Swingley, 2009). Young infants do not reliably saccade towards a known visual stimulus until several hundred milliseconds after hearing it named (~200-400ms; Canfield & Haith, 1991; Fernald et al., 1998; Haith et al., 1988, but see Canfield et al., 1997). As such, fixations prior to this time are unlikely to reflect meaningful responses to spoken stimuli. As the familiarisation trials (i.e., pre-labelling period) did not include any labelling, fixations from the onset through to the offset of the trial were processed.

2.4.6.3 Processing Stages and Inclusion

Prior to analysis, looking time data was processed in stages for each infant using several custom R scripts. First, looking time annotations exported from ELAN were linked with infants' details (e.g., sex, age, counterbalance order) and trials flagged for exclusion

[9] This is due to items being organised into yoked pairs. The computation results in the same value for each item which makes reporting the items individually mathematically redundant. Take the following example. Below are 2 trials featuring the *bite-clap* verb pair. For one of these trials, *bite* is the target. For the other, *clap* is the target. In parentheses is the proportion of time the infant spent looking at that stimulus. The correction for the *bite* item is the proportion looking at *bite* when the distractor (.60) minus the proportion looking at *bite* when the target (.75). This gives a value of .15. When completing the same computation for *clap*, the value is also .15. Thus, items are reported in pairs.

Trial Number	Left Stimulus	Right Stimulus	Target
Trial 1	Bite (.75)	Clap (.25)	Bite
Trial 2	Bite (.60)	Clap (.40)	Clap

during pre-screening were removed. Second, trial details (e.g., verb pair, target item, target position) were linked with infants' looking behaviour and looking proportions towards target and distractor items were calculated. Trials where infants looked at the stimuli for less than 50% of the window of interest were removed, broadly aligned with common thresholds discarding trials in gaze-based tasks (e.g., Bergelson & Swingley, 2015; Gambi et al., 2020). Finally, infants' target looking proportions were corrected for stimulus preference using the post-labelling correction method described in section **2.4.6.1**.

2.4.7. Data Analysis

All analyses were performed using R Statistical Software (R Core Team, 2020). Within R, data manipulation and plots were completed with the *Tidyverse* packages (Wickham et al., 2019) and data analyses were completed using the *rstatix* package (Kassambara, 2021). Visual inspections of all variables revealed non-normal distributions or were classified as discrete (i.e., not continuous) variables and, therefore, non-parametric tests were used throughout. Statistical significance was assessed at an α of .05. Across age groups, infants were evenly split between the two counterbalance orders. Preliminary analyses revealed there were no differences in infants' target looking between counterbalanced orders, Mdn = -0.012, 95% CI [-0.08, 0.05], p = .708. Thus, data was collapsed across counterbalanced orders for all subsequent analyses. The materials, data, and analysis scripts are available at https://osf.io/mbn94/?view_only=8f9e3fd67e3d4fc5a7eb562626229b12.

2.4.7.1 Measuring Verb Comprehension in 10- and 14-month-olds

To assess 10- and 14-month-olds' verb comprehension in the looking while listening task, several analyses were completed across and between verb pairs. Infants were included in analyses if they contributed to a sufficient number of verb pairs. Infants were required to contribute data to at least three of the verb pairs to be kept in the analysis. No infants were excluded as a result of these criteria. Further, looking scores per verb pair were also inspected to check if any infants had multiple outlier scores (i.e., looking scores that were 2.5 SDs above or below the mean). No infants in the sample had more than two outliers and, thus, none were not excluded from analyses due to outliers. Any individual outlier trials (i.e., individual scores 2.5 SDs above or below the mean) were removed prior to data analysis (n = 4). Mean scores over infants and items were calculated after outlier removal.

Wilcoxon tests were calculated across analyses as these tests assess a distribution-free measure of central tendency, the psuedomedian (also known as the Hodges-Lehman Estimate). Analyses, by age-group, measuring verb comprehension via target looking scores were one-sample Wilcoxon Signed Rank tests, measured against a criterion of zero. Analyses comparing target looking between 10- and 14-month-olds were two-sample Wilcoxon Signed Rank tests and the estimated difference in medians. The *wilcox_test()* function from *rstatix* was used to calculate these tests. All verb comprehension analyses were one-tailed, as target looking was predicted to be greater than zero. Effect sizes (*r*) were computed with *wilcox_effsize()*[10]. Ninety-five percentage confidence intervals are reported both for median scores[11] and effect sizes.

2.4.7.2 Associations Between Verb Comprehension and Infants' Actions and Motor Development

To assess links between infants' verb comprehension on the looking while listening task and their motoric experiences, several analyses were conducted. For associations, Spearman's rank correlations were computed with *cor_test()*. Examinations of differences in group averages were assessed with Two-Sample Wilcoxon Signed-Rank tests with *wilcox_test()*. All tests described below were two-tailed.

2.4.7.2.1 Associations Between Target Looking and Motor Development. First, I explored links between infants' looking behaviour (i.e., target looking across infants and verb-pairs) and their EMQ scores. Spearman's Rank correlations were computed for all analyses. These were conducted both across infants, and separately for each age group. I also assessed whether there were associations between infants' target looking and sub-scales of the EMQ that specifically measure gross motor (e.g., whole body actions) development and fine motor (e.g., manual actions) development. These were conducted both across infants, and separately for each age group. Five infants had missing EMQ scores (composite and

[10] *r* for effect size is calculated as the Z statistic divided by the square root of the sample. This returns a correlation coefficient between 0 and 1.

[11] It is important to note that in one-sided hypothesis tests (i.e., directional hypothesis tests), when computing the confidence interval around the parameter of interest, here the pseudomedian, one bound of the confidence interval will always be limited to either ∞ or -∞ depending on the direction of the hypothesis (Lakens, 2022). That is, the interval extends from ∞ or -∞ to a value beyond the observed parameter. Here, all tests predicted that the group estimate would be "greater than" zero, thus the upper bound of all confidence intervals will have a value of ∞. In designs like the present study, logic dictates a limit on this value because it is known that the value cannot exceed a known limit. Here, looking scores are bound between -1 and 1, and thus, the upper confidence interval will always be limited to 1, but is reported throughout as ∞.

subscale scores: 4 x 10-month-olds, 1 x 14-month-old).

2.4.7.2.2 Associations Between Target Looking and Communicative Action/Gesture Skills. Links were also examined between infants' target looking on the looking while listening task and their communicative action and gesture scores on the UK-CDI: A&G. Spearman's Rank correlations were computed for all analyses. These were conducted both across infants, and separately for each age group. Three infants had missing UK-CDI: A&G scores (2 x 10-month-olds, 1 x 14-month-old).

2.4.7.2.3 Associations Between Target Looking and Infants' Actions. Associations between infants' ability the perform actions associated with the verbs in the looking task and their target looking on the looking while listening task were explored. Specifically, I explored whether there was an association between the number of actions caregivers reported that infants could do and their target looking. Visualisations of infants' target looking were non-normal and the number of actions infants could do resulted in count data (i.e., discrete data which is not classified as continuous). Thus, non-parametric Spearman's Rank correlations were used as this test uses the ranks of the values instead of the raw values, enabling correlations between mixed data types to be explored. These were conducted both across infants and separately for each age group. Three infants had missing data for action production (2 x 10-month-olds, 1 x 14-month-old). As described in the Method section, infants' ability to perform an action was assessed in the UK-CDI: Actions and Gestures section by selecting questions that queried parents on the ability to perform the actions associated with the looking task (answering "yes" or "no"). Actions associated with three items from the verb comprehension task ("clap", "kiss", "wave") featured in the "First Communicative Gestures" section, which uses a different response scale. Here, caregivers are asked to indicate if their infant does not yet perform an action ("Not yet"), occasionally performs it ("Sometimes"), or whether they perform it frequently ("Often"). As the current research question was concerned with whether infants could perform an action, rather than how often, responses of "not yet" were treated as "no", whereas scores of "sometimes" and "often" were treated as "yes". Actions associated with "drinking" and "walking" were assessed across two items. This was because drinking is assessed twice in the UK-CDI: A&G (i.e., ability to drink from a cup compared to ability to imitate drinking with toys) and walking ability was measured separately for supported compared to unsupported walking (see **Appendix B** for full list of items). Therefore, in total, 12 questions examined infants' ability to perform actions associated with verbs in the looking task, with scores ranging from 0 to 12.

2.4.7.2.4 Differences in Target Looking Between Non-Walkers, Supported Walkers, and Independent Walkers. I also explored whether there were any differences in performance on the looking task between non-walkers, infants' that could walk with support, and infants' able to walk independently. Caregivers were asked to indicate whether their infant was not yet walking, could walk with support, or could walk without support[12]. A Kruskal-Wallis rank sum test was used to examine any differences in looking behaviour between these infants. The *kruskal_test()* function from *rstatix* was used to calculate this test. This analysis was two-tailed. Three infants had missing data for this analysis (2 x 10-month-olds, 1 x 14-month-old).

2.5.5.2.5. Associations Between Target Looking and Vocabulary Measures

Associations were examined between infants' target looking and vocabulary, as reported by their caregivers on the UK-CDI. The UK-CDI derives two scores by counting (1) the number of words infants understand but do not say, and (2) the number of words infants can say. Correlations between target looking and scores from the full CDI, verb section of the CDI, and verbs from the task were explored. Spearman's Rank correlations were computed for all analyses. These were conducted both across infants, and separately for each age group except in the case of verb production as no children from the 10-month-old group were reported able to produce any verbs.

2.5. Results

2.5.1. Results From the Looking While Listening Paradigm

2.5.1.1 10-month-olds

For 10-month-olds infants, 14/22 (63.6%) had positive target looking values across verb pairs. That is, on average, infants often looked at the target item across different verb pairs. However, analyses of 10-month-olds fixations, over participants and verb pairs,

[12] Caregivers were also asked about their infants' walking ability in the EMQ. However, the EMQ measures granular differences in infants' walking ability (e.g., number of steps infant can climb, walking 4-5 steps with arms raised) and does not easily differentiate between independent walkers, supported walkers, and non-walkers. Thus, I added my own item to easily differentiate between these groups across infants.

revealed that whilst the target looking value was positive, this was not significantly different from zero (see **Figure 2.4**: *Mdn* = 0.024, 95% CI [-0.02, ∞], *p* = .153, *r* = .225, 95% CI [.02, .63]). On average, 10-month-olds looked longer at the target items, for 2/5 verb pairs. Missing values for target looking were evenly spread across analyses. The *cuddle-dance* and *kiss-sit* had missing data for 2 infants, whereas *drink*-walk had missing data for 1 infant. All infants contributed to the *bite-clap* pair. At this age, infants looked significantly longer at the target item for the *drink-walk* pair (*Mdn* = 0.114, 95% CI [0.03, ∞], *p* = .025, *r* = .429, 95% CI [.06, .75]) and the *wave-tickle* pair (*Mdn* = 0.105, 95% CI [0.02, ∞], *p* = .029, *r* = .405, 95% CI [.04, .74]). For *drink-walk*, 13/21 (61.9%) infants had positive target looking values and *wave-tickle* had 15/22 (68.2%). For all other item pairs (*bite-clap, cuddle-dance, kiss-sit*), infants did not look significantly longer at the target item: (*bite-clap*: *Mdn* = -0.056, 95% CI [-0.17, ∞], *p* = .817, *r* = .173, 95% CI [.01, .53]), (*cuddle-dance*: *Mdn* = -0.091, 95% CI [-0.20, ∞], *p* = .918, *r* = .309, 95% CI [.02, .69]), and (*kiss-sit*: *Mdn* = -0.009, 95% CI [-0.09, ∞], *p* = .636, *r* = .063, 95% CI [.01, .54]), respectively. For these items, only 11/22 (50%) infants had positive target looking values for the *bite-clap* pair, 7/20 (35%) for *cuddle-dance*, and 9/20 (45%) for *kiss-sit*.

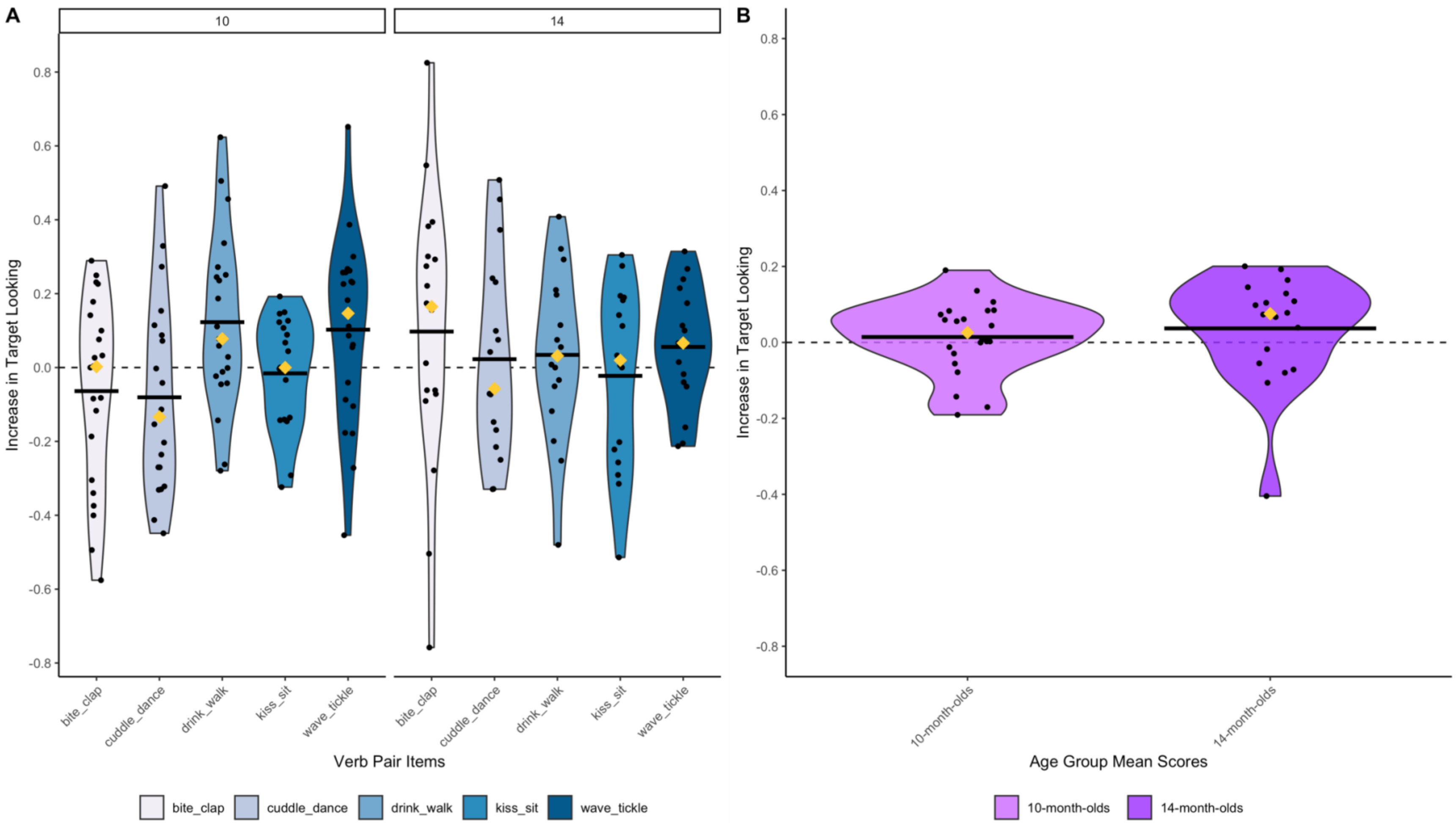
2.5.1.2 14-month-olds

In comparison, 12/18 (66.7%) 14-months-olds had positive target looking values, over verb pairs, looking significantly longer at the target item (see **Figure 2.4**: *Mdn* = 0.056, 95% CI [0.002, ∞], *p* = .045, *r* = .405, 95% CI [.04, .77]). This score was not significantly different from that of the 10-month-olds (estimated difference *Mdn* = 0.041, 95% CI [-0.027, 0.105], p = .229, *r* = .193, 95% CI [.01, .49]). On average, 14-month-olds looked longer at the target items, for 4/5 verb pairs. Missing values for target looking were evenly spread across analyses. The *drink-walk* and *kiss-sit* pair had missing data for 2 infants, whereas the *cuddle-dance* and *wave-tickle* pairs had missing data for 1 infant. All infants contributed to *bite-clap*. A marginally significant effect was found for the *wave-tickle* pair with 11/17 (64.7%) of infants looking longer at the target item (*Mdn* = 0.061, 95% CI [-0.02, ∞], *p* = .066, *r* = .373, 95% CI [.03, .74]). The *bite-clap, cuddle-dance,* and *drink-walk* pairs all had positive target looking values but did not reach significance: (*bite-clap*: *Mdn* = 0.116, 95% CI [-0.06, ∞], *p* = .106, *r* = .303, 95% CI [.03, .69]), (*cuddle-dance*: *Mdn* = 0.013, 95% CI [-0.11, ∞], *p* = .427, *r* = .052, 95% CI [.01, .56]), and (*drink-walk*: *Mdn* = 0.043, 95% CI [-0.07, ∞], *p* = .239, *r* = .188, 95% CI [.01, .65]), respectively. For these items, 11/18 (61.1%)

infants had positive target looking values for the *bite-clap* pair, 8/17 (47.1%) for *cuddle-dance*, and 9/16 (56.3%) for *drink-walk*. Finally, infants did not look longer towards the target item for the *kiss-sit* verb pair (*Mdn* = -0.019, 95% CI [-0.14, ∞], p = .685, r = .084, 95% CI [.01, .58]), with only 9/16 (56.3%) looking longer at the target.

Figure 2.3

By- and across-verb pair difference scores for each age group



Note: A) Shows difference scores for each verb pair, by age group. B) Shows difference scores across verb pairs, computed to show target looking, by age group. Scores greater than zero indicate target looking. Black horizontal bars represent the mean score. Yellow diamonds represent the median score.

2.5.2. Associations Between Verb Comprehension and Infants' Actions and Motor Development

2.5.2.1 Descriptives

Table 2.1

Motor development and action-gesture skill descriptives

Age Group	Measure	N	Mean Score	SD	Range
10-month-olds	CDI: Actions and Gestures	20	14.72	5.39	7.5 – 24
	EMQ Total	18	-0.33	26.89	-70 – 36
	EMQ Fine Motor	18	-4.89	10.55	-19 – 16
	EMQ Gross Motor	18	-6.83	14.54	-47 – 17
	Number of Task Actions	20	7.10	2.05	4 – 11
14-month-olds	CDI: Actions and Gestures	17	27.32	10.84	9 – 50
	EMQ Total	17	72.82	47.47	-21 – 147
	EMQ Fine Motor	17	10.71	15.41	-22 – 35
	EMQ Gross Motor	17	38.06	27.22	-6 – 78
	Number of Task Actions	17	9.77	2.17	5 – 12

Note: EMQ: Early Motor Questionnaire. Total scores and subscale scores for fine and gross motor skills are reported. CDI: Action and Gestures refers to scores from the UK-CDI Action and Gestures section. Number of Task Actions refers to how many of the actions associated with the verbs in the task infants can perform.

2.5.2.2 Associations Between Target Looking and EMQ Scores

There were no significant correlations found between target looking and EMQ scores for the whole sample (r_s = .15, p = .382), or for 10-month-olds (r_s = -.18, p = .483) and 14-month-old (r_s = .32, p = .205), separately. No significant correlations emerged between target looking and the gross motor subscale (i.e., whole body actions), either for the whole sample (r_s = .15, p = .375) or for each age group (10-month-olds: r_s = -.13, p = .601; 14-month-olds: r_s = .30, p = .243). Similarly, no significant correlations emerged between target looking and the fine motor subscale (i.e., manual actions) for either the whole sample (r_s = .14, p = .418) or each age group (10-month-olds: r_s = -.03, p = .903; 14-month-olds: r_s = .15, p = .563).

2.5.2.3 Associations Between Target Looking and Communicative Action/Gesture Skills

No significant correlations were found between target looking and infants' communicative action and gesture scores for the whole sample (r_s = .18, p = .274) or 10-month-olds (r_s = -.14, p = .550). In contrast, for 14-month-olds, a significant moderate positive association was observed between target looking and infants' communicative action and gesture scores (r_s = .51, p = .036).

2.5.2.4 Associations Between Target Looking and Infants' Actions

For the whole sample, a marginally significant positive association emerged between infants' target looking and the number of actions infants could perform associated with the verbs in the looking task (r_s = .30, p = .074). When examining this association by age group, in the 14-month-olds group, a trend towards significance was observed (r_s = .43, p = .081). However, in the 10-month-olds group, no association was observed (r_s = .11, p = .657).

2.5.2.5 Differences in Target Looking Between Non-Walkers, Supported Walkers, and Independent Walkers

Collapsed across age groups, I compared target looking based on whether infants were non-walkers (n = 9), able to walk with support (n = 16), or able to walk independently (n = 12). No differences in target looking between the groups was found, $H(2) = 1.073$, p = .585.

2.5.3. Associations Between Verb Comprehension and Vocabulary Measures

2.5.3.1 Descriptives

Table 2.2

Vocabulary descriptives for the online study

Age Group	Measure	N	Mean Score	SD	Range
10-month-olds	CDI All Words Comprehends	20	69.65	46.2	11 – 197
	CDI All Words Says	20	2.60	3.14	0 – 11
	CDI Verbs Comprehends	20	7.80	7.61	0 – 27
	CDI Verbs Says	20	-	-	-
	Task Verbs Comprehends	20	3.85	2.83	0 – 8
	Task Verbs Says	20	-	-	-
14-month-olds	CDI All Words Comprehends	17	149.59	95.91	12 – 313
	CDI All Words Says	17	8.82	9.48	0 – 35
	CDI Verbs Comprehends	17	22.24	16.75	0 – 51
	CDI Verbs Says	17	0.18	0.39	0 – 1
	Task Verbs Comprehends	17	6.82	2.72	0 – 10
	Task Verbs Says	17	0.06	0.24	0 - 1

Note: CDI: UK Communicative Development Inventory. CDI scores refer to the number of words reported to be understood and said. Comprehension and production scores are reported for all items in the measure, verb items in the measure, and verb items from the task. No 10-month-olds were reported to say any verbs (in the CDI or in the task) and, therefore, no values are reported.

2.5.3.2 Associations Between Target Looking and Vocabulary Measures

Across the whole sample, and by age group, infants' target looking did not correlate with UK-CDI scores, UK-CDI verb scores, nor with scores for verbs in the task (all $p > .10$). See **Appendix D** for correlation coefficients and exact p-values.

2.6. Discussion

Previous research has shown that by 10-months-old, infants have begun understanding more abstract words (Bergelson & Swingley, 2013; Nomikou et al., 2019). However, these studies either did not explore whether infants could extend verbs to action exemplars or did not aim to explore verb comprehension specifically and, thus, included a limited number of verb stimuli in the task. The current study addressed these issues to explore whether 10- and 14-month-old infants understand some early verbs, measured via an online looking while listening paradigm (Fernald et al., 2008; Swingley, 2011). The findings reveal an intriguing insight into the early development of the verb lexicon. As expected, 14-month-old infants linked several verbs with their action referents. That is, 14-month-old infants looked longer, on average, at videos depicting the target action labelled by the verb during the task. However, when examining each verb pair separately, no effects were found, possibly due to reduced power when each item pair is considered separately or due to increased noise. These findings are consistent with previous looking paradigm studies that show infants' looking performance for more abstract words increases around 12- to 14-months-old (Bergelson, 2020; Bergelson & Swingley, 2013). In contrast and contrary to the hypotheses, whilst the majority of 10-month-olds (63.6%) looked longer, on average, towards the target actions, their verb comprehension was constrained to a small number of item pairs in the task. Specifically, these infants associated verbs with the target action for verb pairs *drink-walk* and *wave-tickle*, items which label common daily activities, gestures, and motoric skills in infants' everyday lives. These findings contrast with previous work that suggest that at 10-months, infants can link abstract words with their referents across several task item pairs (Bergelson & Swingley, 2013; Nomikou et al., 2019). These studies used similar looking while listening paradigms but conducted these tasks in laboratory settings with eye-trackers. Like the current study, early uses of these paradigms also relied on manual coding of infants' fixations offline (e.g., Fernald et al., 2001; Swingley, 2005, 2009; Swingley et al., 1999) and recent replications of looking while listening studies using online platforms have largely reported similar patterns of results as their laboratory-based studies (Lapidow et al., 2021; Nelson & Oakes, 2021; Smith-Flores et al., 2022). Whilst it is unlikely that this methodological difference can explain why 10-month-olds did not recognise verbs in the task, Study 2 aimed to address this concern by using a similar design with an eye-tracker for 10-month-olds.

I also examined whether infants' performance during the looking task was associated with their motoric experiences. Across age groups, a marginal positive association was found between infants' ability to perform the actions associated with the verbs in the looking task and their target looking. Interestingly, when examining this relation within each group, only a marginal association held for 14-month-olds. A marginal association was also found between 14-month-olds' looking performance and their gesture and communicative skills, but not for 10-month-olds. Despite previous research reporting links between motor development and word learning, no associations were found between infants' general motor development (including gross motor/whole body action skills and manual action/fine motor skills) and looking performance for the whole sample or for each age group. Finally, no differences in looking scores were found between non-walkers, infants that can walk with support, and independent walkers.

2.7. Study 2: Measuring Verb Comprehension with Eyetracking

2.8. Method

Study 2 used a similar design to Study 1, utilising the same visual and audio stimuli set and counterbalanced trial orders. Caregivers also completed the same demographics questionnaire and parent-report measures described in Study 1. Study 2 had some methodological differences to Study 1, primarily associated with differences in experimental equipment, procedural details, and data processing pipelines. These differences are described in detail throughout the **Method** section. The participants recruited for this study are the same infants that are described in the ERP task in Chapter 3. The current looking while listening task and the ERP task described in Chapter 3 applied different task related exclusion criteria and, thus, included different infants in analyses. As such, the **Participants** section (and associated demographics) described here somewhat vary from those in Chapter 3.

2.8.1. Ethical Approval

This study is associated with ethics application number EC.19.03.12.5595GRA3 and was approved by the Cardiff University School of Psychology Ethics Committee.

2.8.2. Participants

In total, 42 10-month-olds (24 female, *mean Age in months* = 9.94 months, *SD* = 0.34, *range* = 9.44-10.6 months) were tested. Infants in this sample also took part in the ERP task described in Chapter 3, exploring the N400 component. As such, the sample size was based on other N400 ERP studies with younger infants (see Junge et al., 2021, for a review of these studies) and aimed to account for 25-50% data loss associated with infant ERP studies (Hoehl & Wahl, 2012; Stets et al., 2012). Families were recruited via social media post/adverts and the Tiny to Tots Research Panel, a database of families based in Cardiff and South Wales interested in developmental research.

The final sample included 26 10-month-olds (15 female, *M* = 9.86 months, *SD* = 0.31, *range* = 9.44-10.4 months)[13]. All infants were monolingual, English-hearing infants. Infants were classified as monolingual if they were exposed to 75% or more English at home and/or in care settings (e.g., nursery), a common threshold for establishing monolingualism in infant word comprehension studies (Bergelson & Swingley, 2012, 2013, 2015). All infants were born full term (i.e., 37 weeks or later) and had a typical birth weight[14]. All infants were reported as typically developing and did not experience any developmental delays with vision, hearing, communication, or motor development. All families lived in Wales. All infants were reported to be White-British (*n* = 23) or White-Asian (*n* = 3). Sixteen infants from the original sample were excluded from analysis due to technical issues with the eye-tracker (*n* = 10), contributing data to too few verb pairs (*n* = 5), and for not meeting language criteria (*n* = 1)[15].

Families were predominately middle class, with an average household income of £71,500 (*SD* = £33,180, *range* = £21,000-£160,000) before taxes. Most participating parents were women (*n* = 25; 96.2%) and the average age was 34 years (*SD* = 4.94 years, *range* = 20-41 years). One parent completed up to secondary school education (3.8%), one parent received A Level qualifications (3.8%), 12 (46.2%) had Bachelor's degrees, nine (34.6%) had Master's degrees, two (7.7%) had an M.D., P.h.D., or equivalent, and one parent (3.8%) reported having "other" education. All families received a small toy worth approximately £5, an "Infant Scientist" certificate, and a photograph of their infant wearing the EEG cap.

2.8.3. Equipment

Infants' fixations to stimuli were recorded from both eyes using a Tobii Pro X3-120 eye-tracker and continuously sampled at a rate of 120Hz (i.e., 120 samples per second). The eye-tracker was attached to the bottom of a movable 23" monitor (1920 x 1080 pixels) that could be flexibility adjusted to infants' height (to align the centre of the screen with infants' eye line) and distance from the screen (adjusted to approximately 60-65cm) while sat on their caregiver's lap. Audio stimuli were played from the monitor speakers.

[13] A different number of infants were included in the final ERP sample, see Chapter 3.
[14] One infant was reported has having a slightly lower birth weight. Infant was born full term and declared as healthy and typically developing.
[15] Infant heard Welsh as primary language.

2.8.4. Procedure

Caregivers and infants were brought into the lab and made comfortable while the procedure was explained, and a second experimenter entertained the infant. Caregivers then provided written consent. Prior to the experiment starting, the EEG cap was prepared and adjusted onto the infants' head, in preparation for the ERP task described in Chapter 3 (EEG equipment and ERP task procedural details can be found in Chapter 3). Infants were sat on their caregiver's lap in front of the screen. Caregivers were instructed to close their eyes during the eye-tracking task and asked to refrain from interacting with their child during stimuli presentation aside from reorienting their infant towards the screen or soothing them during periods of fussiness. The session was video recorded via a live feed webcam, on top of the monitor, that enabled the experimenter to monitor infant attentiveness and fussiness.

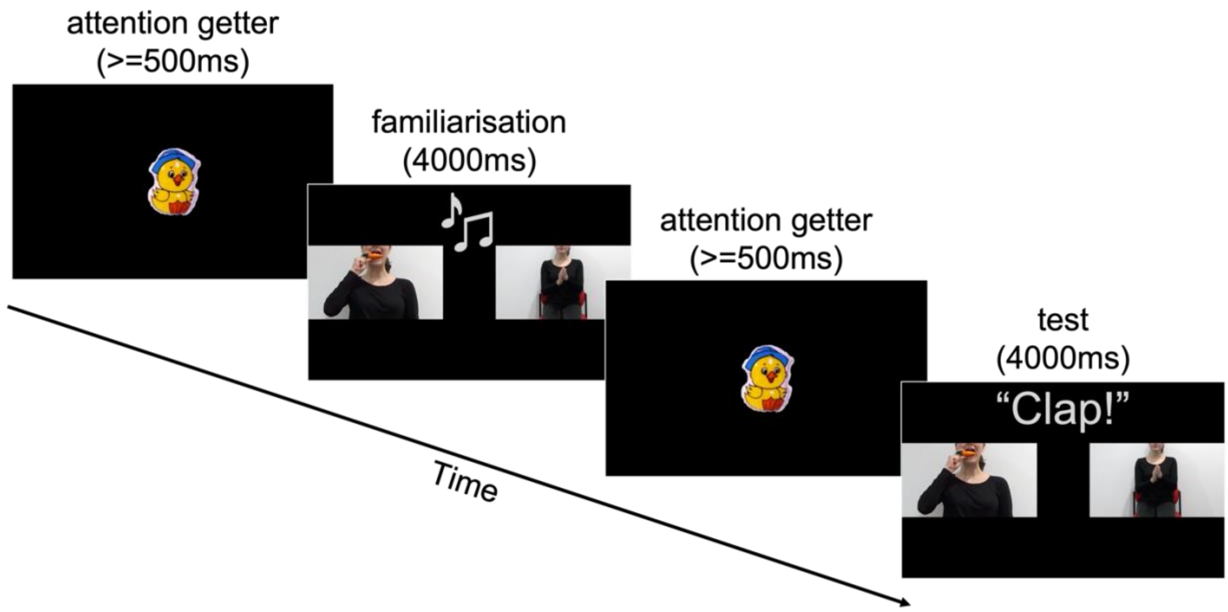
First, infants completed a 5-point calibration sequence until at least four valid points were detected, per eye, or three calibration attempts were made. The calibration sequence consisted of a red dot that traversed to each of the four corners of the screen before moving to the centre of the screen. During this sequence, a keyboard piano was played, via the monitor speakers, to maintain infants' attention. This technique has been used in previous infant studies to maintain or regain attention during calibration sequences (e.g., Vanderwert et al., 2015).

Stimuli were presented with E-Prime 3.0 software (Psychology Software Tools, 2016). Each trial began with an attention getter that directed infants' gaze to the centre of the screen. The attention getter remained until the infant looked at the screen, at which time the experimenter triggered the familiarisation videos. Unlike Study 1, attention getter stimuli used were from the Tobii Pro Infant set. As in Study 1, during familiarisation, infants were presented with a yoked pair of videos, side-by-side, accompanied by music. This familiarised infants with the video stimuli and their location during that trial. This was followed by additional attention getter to reorient infants' gaze to the centre of the screen until the experimenter triggered the test videos. During test trials, infants saw the same videos again accompanied by a spoken label describing the target action. The spoken label onset began with the video onset. Both familiarisation and test trials were 4000ms.

The same number of trials and counterbalanced orders (to counterbalance target side and trial order) were used from Study 1. Infants were randomly assigned to one of the two pseudorandomised orders. **Figure 2.5** shows the task timeline. Testing continued until all trials had been completed, lasting approximately 5 minutes, or until infants' attention could no longer be maintained. If infants were still comfortable and attentive, they then took part in the ERP task which is described in detail in Chapter 3. The eye-tracking task always preceded the ERP task[16], where infants saw individual videos of actions paired with verbs, to avoid potential learning effects from the ERP task.

At the end of the session, infants received a small toy worth approximately £5 and a certificate for participation. After the session, caregivers were sent a URL link to complete the demographic questionnaire, UK-CDI, and EMQ.

Figure 2.4
Trial timeline for the eye-tracking looking-while-listening task



2.8.5. Data Processing

All data preparation were performed in R (R Core Team, 2020) and with the *eyetrackingR* package (Dink & Ferguson, 2015). Areas of interest (AOIs) were defined over each video (768x432 pixels) and trials during which infants fixated on AOIs for less than 50% of the window of interest were removed. As with Study 1, the window of interest for test trials began 367ms through to the end of the trial (4000ms) and for familiarisation trials the whole trial was used (0-4000ms). Proportions of target and distractor fixations within these time windows were computed. Prior to data processing in R, video footage of the session was pre-screened to identify any trials that should be excluded from analysis due to external factors. For example, infant was fussy/distressed or caregiver interference (e.g., pointing, speaking over label). Trials identified during pre-screening were removed from the dataset.

[16] Aside for several infants (n = 9) where the eye-tracker failed and, thus, only the ERP task was presented.

On average, 0.66 test trials (*SD* = 0.89, *range* = 0-3), per infant, were excluded for these reasons. Finally, bias corrections were applied (see **2.4.6.1 Bias Correction** for details).

2.9. Results

The same analyses were conducted as Study 1, aside from analyses that included comparing differences with 14-month-olds. Infants were broadly split between counterbalance orders (n = 11, n = 15). Preliminary analyses revealed there were no differences in infants' target looking between counterbalanced orders, *Mdn* = -0.023, 95% CI [-0.141, 0.117], p = .838. Thus, data was collapsed across counterbalanced orders for all subsequent analyses. Five infants did not contribute to at least three verb pairs and were excluded from analyses. As with Study 1, looking scores per verb pair were inspected to check if any infants had several outlier scores (i.e., looking scores that were 2.5 SDs above or below the mean). No infants in the sample had more than two outliers and, thus, none were excluded from analyses due to the presence of multiple outliers. Any individual outlier trials (i.e., individual scores 2.5 SDs above or below the mean) were removed prior to data analysis (n = 2). Mean scores over infants and items were calculated after outlier removal. Visual inspections of all variables revealed non-normal distributions or were classified as discrete (i.e., not continuous variables) and, therefore, non-parametric tests were used throughout.

As previously described, several infants (n = 15, *mean age* = 10.0 months, *SD* = 0.35, *range* = 9.51-10.50 months) were excluded from Study 2 due to technical difficulties with the eye-tracker (n = 10) and not contributing data to at least three verb pairs (n = 5). This resulted in a smaller sample and, thus, there may insufficient power to detect effects. Indeed, it is possible that the sample size in Study 1 was not large enough to detect verb comprehension in 10-month-old infants. To address this potential issue, additional integrative analyses (see **2.9.4 Integrative Analyses**) are also reported, combining data from 10-month-olds in Study 1 and Study 2 and conducting the same analyses to increase power to detect effects (Lakens & Etz, 2017). This combined dataset resulted in a mean age of 9.99 months (N = 48, *SD* = 0.35, *range* = 9.44-10.60 months).

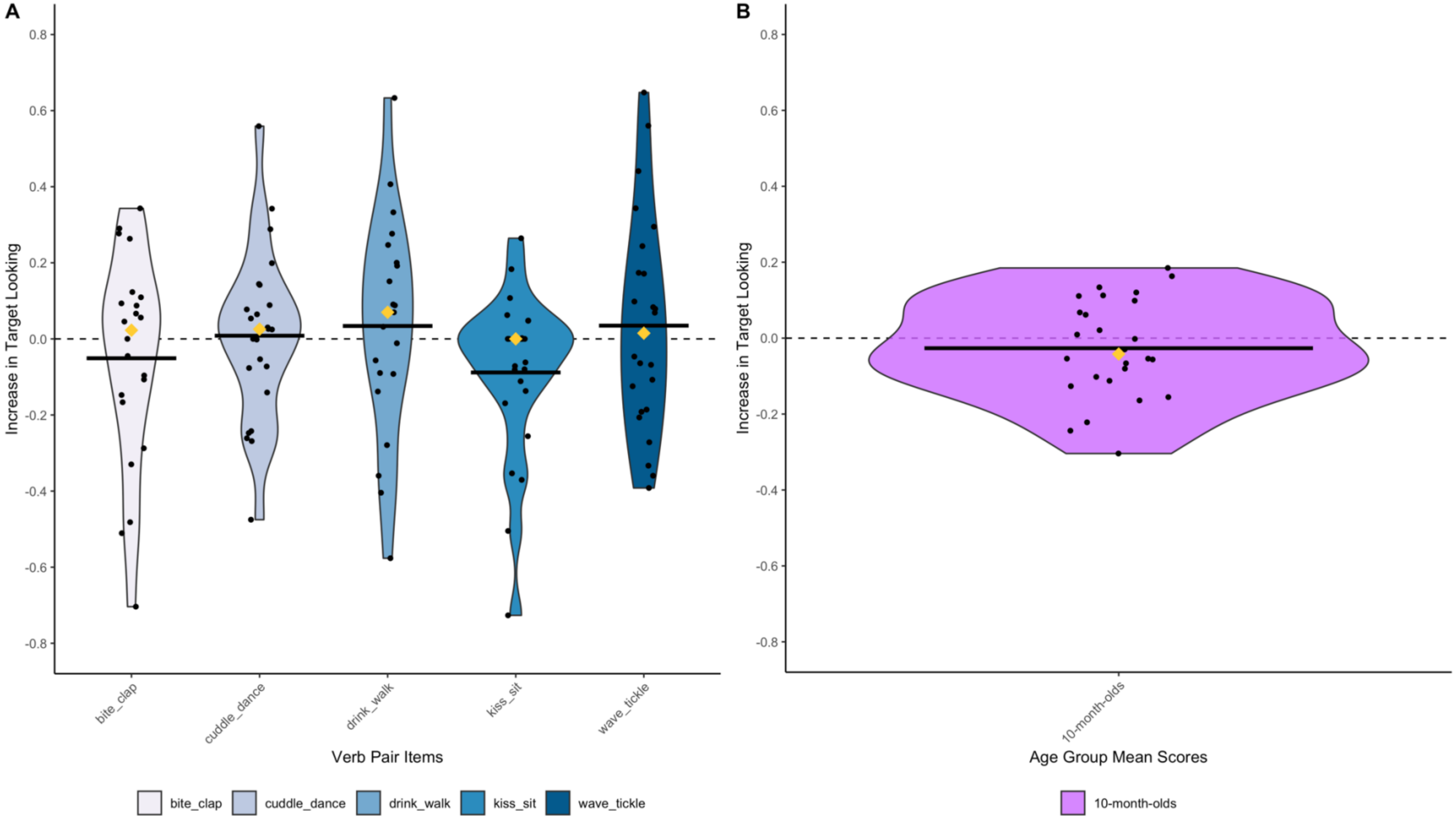
2.9.1. Results From the Looking While Listening Paradigm

Eleven out of 26 (42.3%) 10-month-olds had positive target looking across participants and verb pairs. Analyses of 10-month-olds fixations, over participants and verb pairs, revealed that infants did not, on average, look longer at the target item (see **Figure 2.6**: *Mdn* = -0.023, 95% CI [-0.07, ∞], *p* = .781, *r* = .152, 95% CI [0.01, 0.51]).

The *drink-walk* pair had missing data for 5 infants, *bite-clap* had missing data for 3 infants, *cuddle-dance* had missing data for 2 infants and *kiss-sit* and *wave-tickle* had missing data for 1 infant. Ten-month-olds had average positive looking scores, across infants, for 3/5 verb pairs: *cuddle-dance, drink-walk* and *wave-tickle*. For these items, 13/24 (54.2%) infants had positive looking scores for the *cuddle-dance* pair, 12/21 (57.1%) for *drink-walk,* and 13/25 (52%) for *wave-tickle*. Whilst these verb pairs had positive target looking values, none were significantly different from zero (*cuddle-dance*: *Mdn* = 0.012, 95% CI [-0.08, ∞], *p* = .375, *r* = .073, 95% CI [0.01, 0.49]), (*drink-walk*: *Mdn* = 0.047, 95% CI [-0.07, ∞], *p* = .270, *r* = .140, 95% CI [0.003, 0.54]), and (*wave-tickle*: *Mdn* = 0.018, 95% CI [-0.08, ∞], *p* = .365, *r* = .073, 95% CI [0.01, 0.45]), respectively. Infants did not look significantly longer at the target item for the remaining verb pairs (*bite-clap*: *Mdn* = -0.050, 95% CI [-0.21, ∞], *p* = .810, *r* = .168, 95% CI [0.01, 0.53]), (*kiss-sit*: *Mdn* = -0.093, 95% CI [-0.21, ∞], *p* = .972, *r* = .336, 95% CI [0.02, 0.64]). For these verb pairs, 11/23 (47.8%) infants had positive target looking values for the *bite-clap* pair and only 7/25 (28%) for *kiss-sit*.

Figure 2.5

By- and across-verb pair difference scores



Note: A) Shows difference scores for each verb pair. B) Shows difference scores across verb pairs, computed to show target looking. Scores greater than zero indicate target looking. Black horizontal bars represent the mean score. Yellow diamonds represent the median score.

2.9.2. Associations Between Verb Comprehension and Infants' Actions and Motor Development

2.9.2.1 Descriptives

Table 2.3

Motor development and action-gesture skill descriptives

Measure	N	Mean Score	SD	Range
CDI: Actions and Gestures	25	12.54	5.39	4.5 – 27
EMQ Total	23	-26.87	32.32	-84 - 53
EMQ Fine Motor	23	-10.17	12.24	-28 – 29
EMQ Gross Motor	23	-14	16.89	-50 – 17
Number of Task Actions	25	6.52	1.69	3 - 9

Note: EMQ: Early Motor Questionnaire. Total scores and subscale scores for fine and gross motor skills are reported. CDI: Action and Gestures refers to scores from the UK-CDI Action and Gestures section. Number of Task Actions refers to how many of the actions associated with the verbs in the task infants can perform.

2.9.2.2 Associations Between Target Looking and EMQ Scores

A moderate positive significant correlation emerged between infants' target looking and total EMQ scores ($r_s = .42$, $p = .043$). No significant correlations emerged between target looking and the gross motor subscale (i.e., whole body actions) for the whole sample ($r_s = .28$, $p = .195$) or the fine motor subscale (i.e., manual actions; $r_s = .28$, $p = .191$).

2.9.2.3 Associations Between Target Looking and Communicative Action/Gesture Skills

No significant correlation was found between target looking and infants' communicative action and gesture scores ($r_s = -.05$, $p = .804$).

2.9.2.4 Associations Between Target Looking and Infants' Actions

No significant correlation emerged between infants' target looking and the number of actions infants could perform associated with the verbs in the looking task ($r_s = -.32$, $p = .123$).

2.9.2.5 Differences in Target Looking Between Non-Walkers and Supported Walkers

As no infants in the sample were reported able to walk independently, only non-walkers and infants able to walk with support were compared. In contrast to Study 1, infants reported as able to walk with support (*n* = 17) had marginally lower target looking values than infants that were reported not able to walk with support (*n* = 8, estimated difference *Mdn* = 0.114, 95% CI [-0.02, 0.19], *p* = .098, *r* = .338, 95% CI [0.04, 0.64]).

2.9.3. Associations Between Verb Comprehension and Vocabulary Measures

2.9.3.1 Descriptives

Table 2.4
Vocabulary descriptives for the eyetracking study

Measure	N	Mean Score	SD	Range
CDI All Words Comprehends	26	55.54	42.23	0 – 149
CDI All Words Says	26	2.5	4.02	0 – 16
CDI Verbs Comprehends	26	8.54	8.35	0 – 26
CDI Verbs Says	26	-	-	-
Task Verbs Comprehends	26	4.04	2.97	0 – 10
Task Verbs Says	26	-	-	-

Note: CDI: UK Communicative Development Inventory. CDI scores refer to the number of words reported to be understood and said. Comprehension and production scores are reported for all items in the measure, verb items in the measure, and verb items from the task. No 10-month-olds were reported to say any verbs (in the CDI or in the task) and, therefore, no values are reported.

2.9.3.2 Associations Between Target Looking and Vocabulary Measures

Infants' target looking did not correlate with UK-CDI scores comprehension (r_s = .02, *p* = .934) or production scores (r_s = .08, *p* = .698), UK-CDI verb comprehension scores (r_s = .001, *p* = .997), nor with comprehension scores for verbs in the task (r_s = -.07, *p* = .731).

2.9.4. Integrative Analyses: Combining 10-month-olds Data from Study 1 & 2

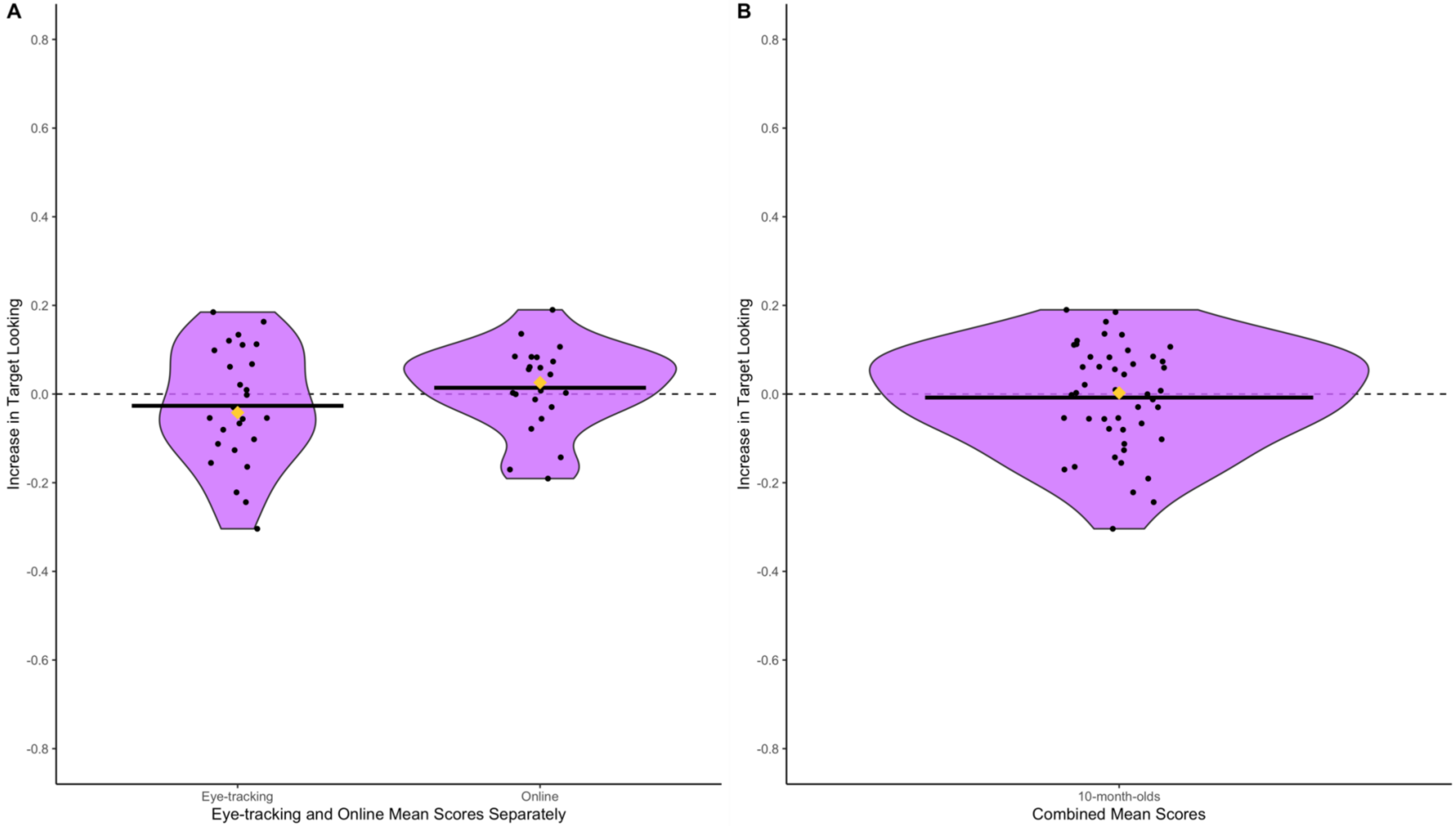
Prior to conducting the integrative analyses, I first established that there were no significant differences in verb pair and target looking between the two methods of data collection. Two sample Wilcoxon Signed Rank tests (reporting estimated median differences) confirmed that there were no significant differences between target looking over verb pairs (*Mdn* = -0.043, *p* = .339) or for each verb pair (*bite-clap*: *Mdn* = 0.002, *p* = .982; *cuddle-dance: Mdn* = 0.095, *p* = .185; *drink-walk*: *Mdn* = -0.072, *p* = .410; *kiss-sit*: *Mdn* = -0.062, *p* = .319; *wave-tickle*: *Mdn* = -0.093, *p* = .248). Thus, the datasets were combined. Analyses from Study 2 were repeated with the combined dataset.

2.9.4.1 Results From the Looking While Listening Paradigm

Twenty-five out of 48 (52.1%) 10-month-olds had positive target looking values over participants and verb pairs. Analyses of 10-month-olds' fixations, across participants and verb pairs, revealed that infants did not on average look longer at the target item (see **Figure 2.7**: *Mdn* = -0.0001, 95% CI [-0.03, ∞], *p* = .522, *r* = .007, 95% CI [0.004, 0.33]). The *drink-walk* pair had missing data for 6 infants, *cuddle-dance* had missing data for 4 infants, *bite-clap* and *kiss-sit* had missing data for 3 infants, whereas *wave-tickle* had missing data for 1 infant. Ten-month-olds had positive target looking values, across infants, for 2/5 verb pairs: *drink-walk* and *wave-tickle* (**Figure 2.8**). For these pairs, 25/42 (59.5%) infants had positive target looking values for the *drink-walk* pair, and 28/47 (59.6%) for *wave-tickle*. Infants looked significantly longer at the target item for the *drink-walk* pair (*Mdn* = 0.081, 95% CI [0.01, ∞], *p* = .032, *r* = .287, 95% CI [0.03, 0.57]) and marginally longer at the target item for the *wave-tickle* pair (*Mdn* = 0.065, 95% CI [-0.005, ∞], *p* = .068, *r* = .219, 95% CI [0.01, 0.49]). Infants did not look longer at the target item for the remaining verb pairs (*bite-clap*: *Mdn* = -0.055, 95% CI [-0.14, ∞], *p* = .894, *r* = .172, 95% CI [0.01, 0.47]), (*kiss-sit*: *Mdn* = -0.048, 95% CI [-0.11, ∞], *p* = .940, *r* = .207, 95% CI [0.01, 0.46]), (*cuddle-dance*: *Mdn* = -0.041, 95% CI [-0.10, ∞], *p* = .799, *r* = .124, 95% CI [0.004, 0.43]). For these verb pairs, 22/45 (48.9%) infants had positive target looking values for the *bite-clap* pair, 16/45 (35.6%) for *kiss-sit*, and 20/44 (45.5%) for *kiss-sit*.

Figure 2.6

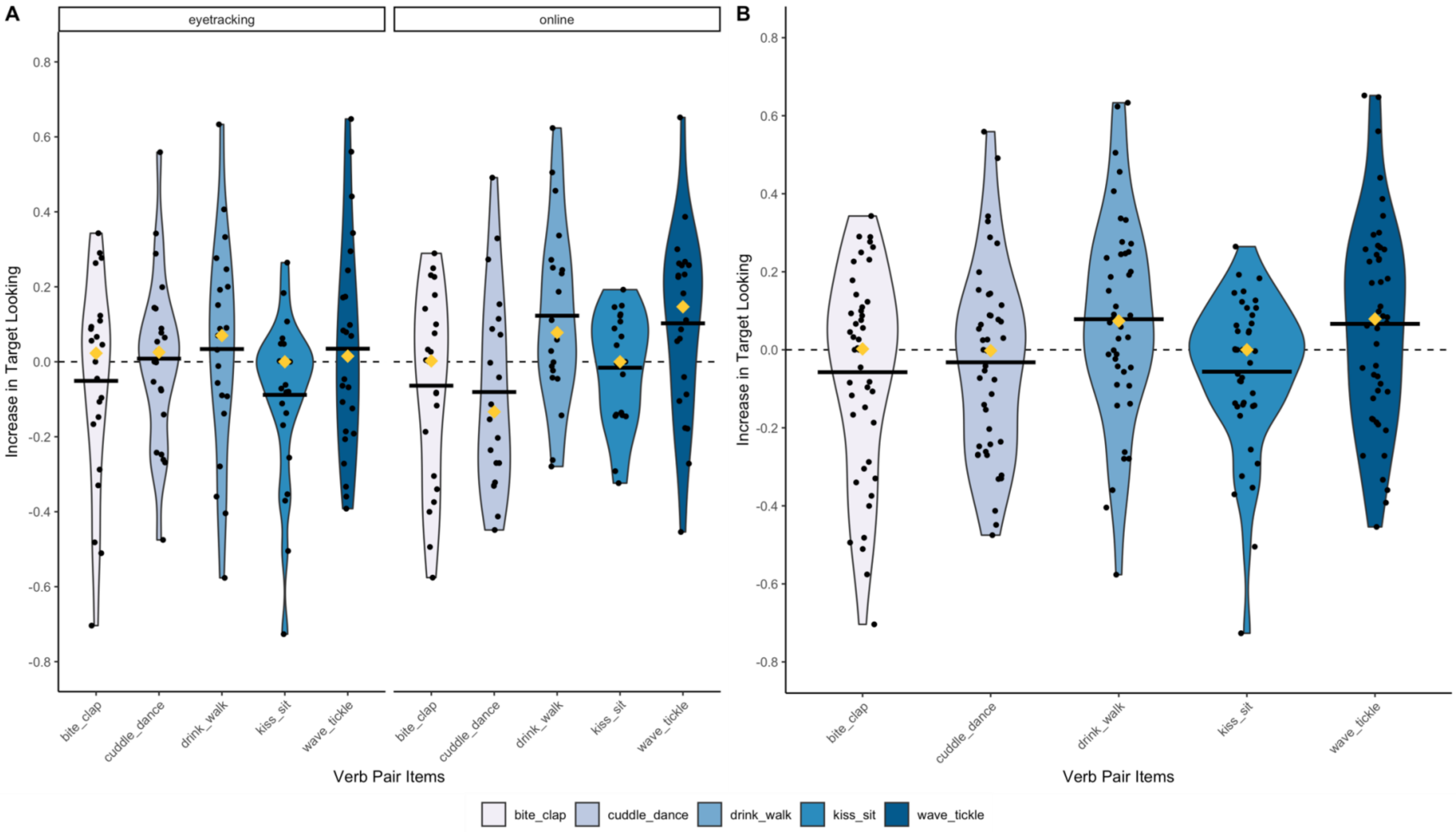
Across verb pair difference scores



Note: A) Average difference scores, across verb pairs, by study (Study 1 – right, Study 2 – left). B) Combined average difference scores, across verb pairs. Black horizontal bars represent the mean score. Yellow diamonds represent the median score.

Figure 2.7

By verb pair difference scores



Note: A) By verb pair difference scores by study (Study 1 – right, Study 2 – left). B) Combined verb pair difference scores. Black horizontal bars represent the mean score. Yellow diamonds represent the median score.

2.9.4.2 Associations Between Verb Comprehension and Infants' Actions and Motor Development

2.9.4.2.1 Associations Between Target Looking and EMQ scores. No significant correlation emerged between infants' target looking and total EMQ scores (r_s = .18, p = .272). When examining this relation by motor skills type, no significant correlations emerged between target looking and the gross motor subscale (i.e., whole body actions; r_s = .13, p = .417) or the fine motor subscale (i.e., manual actions; r_s = .18, p = .264).

2.9.4.2.2 Associations Between Target Looking and Communicative Action/Gesture Skills. No significant correlation was found between target looking and infants' communicative action and gesture scores (r_s = -.11 p = .475).

2.9.4.2.3 Associations Between Target Looking and Infants' Actions. No significant correlation emerged between infants' target looking and the number of actions infants could perform associated with the verbs in the looking task (r_s = -.15, p = .311).

2.9.4.2.4 Differences in Target Looking Between Non-Walkers and Supported Walkers. As only one infant in the sample was reported as able to walk independently, only non-walkers (n = 15) and infants able to walk with support (n = 29) were compared. There were no significant differences in target looking between infants reported as able to walk with support and non-walkers (*Mdn* = 0.048, 95% CI [-0.04, 0.01], p = .238, r = .181, 95% CI [0.01, 0.44]).

2.9.4.3 Associations Between Verb Comprehension and Vocabulary Measures

2.9.4.3.1 Associations Between Target Looking and Vocabulary Measures. Infants' target looking did not correlate with UK-CDI scores comprehension (r_s = -.01, p = .940) or production scores (r_s = -.03, p = .866), UK-CDI verb comprehension scores (r_s = -.12, p = .429), nor with comprehension scores for verbs in the task (r_s = -.11, p = .483).

2.10. Discussion

The looking data collected in the lab (Study 2) showed a similar trend of results as were found online (Study 1) with the findings showing that 10-month-olds failed to look longer at target items, both between and across verb pairs. These findings suggest that, in both studies, 10-month-olds were unable to understand the verbs in the task. To ascertain whether these findings may be due to smaller sample sizes and reduced statistical power, an integrative approach combining 10-month-olds data from across Study 1 and Study 2 was adopted. Prior to merging study data, analyses revealed that there were no differences in infants' target looking between studies. Analyses with the combined data revealed a similar pattern of results, demonstrating that 10-month-olds recognise a small number of verb items but broadly find verb understanding a challenging task. Aside from a moderate association between looking performance and overall motor development (Study 2 only), no other associations between performance on the looking task and motoric experiences or vocabulary development were found.

2.11. General Discussion

Early in infancy, children already understand many more words than they can say (Fenson et al., 1994; Goldin-Meadow et al., 1976). Compared to nouns, children find verbs challenging to learn (Gentner, 1978, 2006; Gentner & Boroditsky, 2001). Nonetheless, verbs still feature in children's earliest productive vocabularies (Maguire et al., 2006). Research shows us that nouns feature in infants' receptive vocabulary as early as 6-months-old (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012). But when do children begin understanding their first verbs? Across two studies using a looking while listening paradigm, the present research examined whether 10-month-old (Study 1 & 2) and 14-month-old (Study 1) infants linked early verbs with novel action exemplars. These studies focused on 10-month-olds as infants of this age are reported to demonstrate event processing and action conceptualisation skills (e.g., Göksun et al., 2011; Konishi, Pruden, et al., 2016; Konishi, Stahl, et al., 2016; Levine et al., 2018; Pruden et al., 2012, 2013; Pulverman et al., 2013; Song et al., 2016), can segment some words from speech (Jusczyk, Hohne, et al., 1999; Jusczyk, Houston, et al., 1999; Jusczyk & Aslin, 1995; Saffran et al., 1996; Werker & Hensch, 2015) and can associate some abstract words with their referents (Bergelson & Swingley, 2013), all which are pre-requisite skills necessary for verb learning. Fourteen-month-olds were also tested in Study 1 as around this age, infants typically experience a sharp increase in word segmentation and comprehension abilities (Bergelson, 2020; Nazzi et al., 2005). These studies found that, contrary to the hypothesis, 10-months-olds had a fragile understanding of verbs, with verb recognition constrained to a small number of verb items associated with common everyday actions. Specifically, whilst 10-month-olds linked some verbs with their referents, infants failed to look longer at the target items across the task. As expected, across items, 14-month-olds looked significantly longer at the target action after hearing it labelled. In the following sections, I begin by discussing 10-month-olds failure to recognise verbs, when previous studies show infants are already able to link some early abstract words with their referents. I then discuss 14-month-olds success in recognising verbs across the task. Possible explanations for these findings are offered in turn and how later chapters in this thesis may offer additional insight. Finally, associations between infants' target looking and parent report measures of motoric experiences and language skills are discussed.

Ten-month-olds' performance on the looking while listening task (i.e., failing to look longer at the target item, across verb pairs) may demonstrate that, at this early stage of linguistic and cognitive development, infants struggle to map verbs onto action concepts. Gentner (1982, 2006) previously argued that children's difficulty with verbs is unlikely due to difficulty conceptualising events, but rather difficulty mapping verbs onto actions and figuring out which semantic elements a verb describes. Certainly, event processing and conceptualisation skills are evident during infancy, but the ability to map abstract words onto abstract concepts (and the relevant skills that support this process) are likely still developing at this age. For example, when faced with challenges of verb learning in which identifying the intended referent is a difficult task (for both children and adults; Gillette et al., 1999), older children often exploit social (e.g., eye gaze; Nappa et al., 2009) and linguistic cues (e.g., syntax; Yuan & Fisher, 2009) to gather information about a verb. At 10-months-old, infants are just beginning to hone their gaze following abilities (Beier & Spelke, 2012; Brooks & Meltzoff, 2005) and only start employing knowledge of sentence structure to identify novel verbs during the second year of life (Jin & Fisher, 2014). Thus, 10-month-olds may have limited abilities to utilise cues present in their environment to identify the referent of a verb.

One the other hand, younger infants (who say no to few words and have smaller receptive lexicons) may rely on highly supportive environments to extend familiar verbs to new exemplars. As research with children shows, verb learning is a challenging task

(Gentner, 1978, 1982, 2006; Gentner & Boroditsky, 2001) and children often rely on supportive cues to identify the referents of verbs (e.g., Aussems et al., 2021; Aussems & Kita, 2020; Childers, Paik, et al., 2016; Childers, Parrish, et al., 2016; Gampe et al., 2016; Haryu et al., 2011; Maguire et al., 2008). In previous looking while listening tasks exploring noun comprehension (Bergelson & Swingley, 2012, 2015) and abstract word/phrase knowledge (Bergelson & Swingley, 2013; Nomikou et al., 2019), infants heard target items spoken by their caregiver rather than via recorded audio, like the current studies. Previous studies suggest that young word learners' word-referent links are fragile and dependent on carefully scaffolded scenarios to extend a known word to a new exemplar (Bergelson & Swingley, 2018; Parise & Csibra, 2012). This work shows that infants aged between 8- and 11-months only respond to familiar noun items when spoken by their caregivers compared to a new speaker (Parise & Csibra, 2012), whereas older infants (and, surprisingly, also younger infants) respond equally to familiar and unfamiliar speakers (Bergelson & Swingley, 2018). Replications of Bergelson and Swingley's (2012) study have failed to reproduce the same results when using pre-recorded spoken stimuli (Steil et al., 2021; but also see, Tincoff & Jusczyk, 1999, 2012) suggesting that familiar speakers may be important for younger infants. Whilst it is not possible to test in the current design, 10-month-olds' limited verb comprehension in the current tasks may have, in part, been impeded by hearing labels from an unfamiliar speaker.

Further, previous studies have often embedded verbs or abstract words in sentences or accompanied by carrier phrases (Bergelson & Swingley, 2013; Nomikou et al., 2019). In the current studies, infants heard verbs in isolation. Syntactic bootstrapping approaches suggest that children successfully learn verbs by using knowledge of other words in the sentence and syntax to figure out the meaning of words (Fisher et al., 2010, 2020). Whilst this approach primarily focuses on how children come to learn a novel verb, rather than recognise a novel exemplar, it is feasible that infants may also rely on support from syntax when identifying the referent of a known verb in novel situations. For example, some research has shown that when identifying verbs, children benefit from them being contained in common verb frames (e.g., "It's ___ing!"; He & Lidz, 2017) and when verbs are preceded by function words (e.g., "*She is* dancing"; de Carvalho et al., 2019). However, there is currently little evidence to suggest that infants make use of such cues to identify verbs before the second year of life (Jin & Fisher, 2014; Yuan & Fisher, 2009).

It is also possible that the simultaneous presentation of actions side-by-side was challenging for 10-month-old infants. Looking behaviour in such designs can sometimes be influenced by visual preference, resulting in findings that seem to suggest infants failed to discriminate between the two exemplars (Aslin, 2007). However, it is also possible that, whilst hearing a verb, abstracting the correct referent from two simultaneous dynamic stimuli is too challenging for younger infants. For example, Pruden et al. (2012) previously demonstrated that 10- to 12-month-olds can sometimes struggle to detect a target action at test when complex stimuli are used even though 13- to 15-month-olds succeeded in this task. Interestingly, in a follow-up study, the authors reported that 10- to 12-month-olds could succeed in identifying the target action when a simplified display with reduced attentional demands was used. It is possible that at this younger age, infants may only be able to identify verb referents in simplified designs or designs that enable infants to first appraise the visual information before then hearing a verb. For example, the auditory overshadowing hypothesis suggests that, when presented with simultaneous visual-auditory displays, younger infants will often prioritise processing auditory information resulting in an attenuation of visual processing (e.g., Robinson & Sloutsky, 2019). Possibly, infants' performance may improve in designs where they have the opportunity to prioritise visual information before a verb utterance is heard (see Chapter 3). Therefore, whilst it is not possible to test here, infants' failure to understand verbs in our task may be a result of less optimal conditions for verb recognition. As such, future studies should aim to explore younger infants' verb comprehension accompanied by supportive cues (e.g., alongside function words, verb frames, and spoken by familiar speakers). In Chapter 3, I describe an additional study exploring verb comprehension in 10-month-olds that measured infants verb comprehension using implicit, neural responses (i.e., less prone to visual preference) and a less attentionally demanding task.

Fourteen-month-olds, in Study 1, looked longer at target actions after hearing them labelled with verbs. These findings are consistent with previous research applying behavioural (Goldin-Meadow et al., 1976) and looking time (Bergelson & Swingley, 2013) measures of word comprehension reporting that 14-month-olds understand verbs. Why were 14-month-olds successful in recognising verbs across the task? At 14-months, infants have already acquired sophisticated language and event processing skills that facilitate mapping words onto more abstract concepts. For example, 14-month-olds are rapidly adding words to their receptive (Bergelson, 2020; Bergelson & Swingley, 2012, 2013, 2015) and productive vocabulary (Fenson et al., 1994), can successfully segment verbs from speech (Nazzi et al., 2005), and demonstrate the ability to rapidly associate novel words with their referents (Friedrich & Friederici, 2008; Werker et al., 1998). Further, at this age, infants demonstrate capabilities to exploit sentence structure and the types of words in a sentence to understand novel verbs (Jin & Fisher, 2014), nouns, and adjectives (Waxman & Booth, 2001). Infants are also receiving more verb labelling events from their parents as they age and continue to acquire new motor skills, providing new opportunities to be exposed to novel verbs (West et al., 2022). The present findings corroborate other recent looking while listening tasks that report infants' abstract language capabilities improving around 14-months-old (Bergelson & Swingley, 2013, 2015). However, when exploring infants' looking behaviour for each verb pair, 14-month-olds target looking was at chance. Given that for most verb pairs, the majority of infants (i.e., more than 50%) looked longer at the target, it is possible that there was insufficient power to detect effects when examining by verb pair or that different infants recognised different verbs.

In Chapter 1 and earlier in this chapter, I outlined literature highlighting links between infants' motor development and vocabulary, both concurrently and longitudinally. I also described research suggesting that infants receive increased verb input when engaging in actions and hypothesised that infants' verb comprehension would be linked with their motor development and abilities to perform actions/gestures. Examinations of links between infants' performance on the looking tasks and their motoric experiences (e.g., motor development, communicative gesture skills, walking ability) presented a mixed picture across the studies. A positive association was found between 10-month-olds looking performance and overall motor development but only in Study 2. Given that this association was not found in Study 1 or during the integrative analyses, it is possible this was a spurious correlation. An association was also found between 14-month-olds' looking scores and ability to perform actions associated with the task. Previous studies have shown that infants' gesture capabilities are associated with their receptive language skills (Colonnesi et al., 2010) and that gesture use and practice performing associated actions can help older children understand novel verbs (Gampe et al., 2016). Beyond these findings, however, infants' performance on the task was not associated with their motor development (gross or fine), communicative gesture capabilities or walking ability. One possible explanation for the failing to detect any correlations between infants' verb understanding and their motor/action/gesture development is that links between these domains may hold particular importance later in development. For example, younger infants (13-months-old and younger) receive far less verb input from their caregivers compared to older infants (West et al., 2022). As infants master independent walking, caregivers almost double their verb production (Schneider & Iverson, 2022). In the current studies, it is possible that at these younger ages, infants' motor abilities are not yet developed enough to frequently prompt verb-naming events. This may be especially true as very few infants in the current samples were reported as able to walk independently. In Chapter 4, I provide additional insight into this matter by exploring links between motor development and verb comprehension across the first two years of life.

Finally, across studies, no associations were found between infants' performance on the task and their parent-reported receptive and productive vocabularies. These findings align with previous work that shows parents of younger infants (i.e., infants with little to no words in their receptive vocabulary) tend to either underestimate (Houston-Price et al., 2007) their infants' word knowledge or are subject to response biases (see Frank et al., 2017, for discussion). Further, these findings corroborate work that shows infants' looking performance on looking while listening tasks is rarely associated with CDI scores (except for much older infants; Bergelson & Swingley, 2013, 2015). This is thought to be due to parents having difficulty estimating infants' word knowledge before they begin saying many words.

2.12. Conclusion

The present studies aimed to provide insight into infants' early word comprehension by directly testing young infants' understanding of verbs. Here, I show that at 10-month-olds, infants generally fail to link verb items with novel action exemplars, recognising only a small number of verbs in the task. In contrast, 14-month-olds understood verbs across the task, in line with previous research reporting increased event processing and word recognition skills at this age. Potential explanations for 10-month-olds difficulty in understanding verbs in the task were discussed. Whilst it is possible that infants do not understand verbs at this early stage of development (but see Chapter 3), I discussed that infants' verb recognition may be dependent on additional supportive cues (e.g., carrier phrases, verb framing, familiar speakers) which were not available in this paradigm. Alternatively, younger infants' may have struggled to abstract the correct referent due to the attentional demands of two dynamic stimuli being presented simultaneously or may have been influenced, in part, by visual preference. In the following chapter, I describe an additional task utilising event-related potentials to measure 10-month-olds verb comprehension, addressing some of these considerations by utilising an implicit measure of word understanding.

Chapter 3. Exploring Verb Comprehension with Event-Related Potentials

3.1. Introduction

In Chapter 2, I described two studies measuring verb comprehension in English-hearing infants aged 10- and 14-months-old using looking while listening tasks, both in the lab and online. These studies revealed that 14-month-old infants looked longer on average to target verbs across the task (tested online), demonstrating that they associated verbs with action exemplars. In contrast, 10-month-olds failed to reliably look longer at target items overall, and only evidenced comprehension of a small number of verbs. These findings may suggest that, at 10 months, infants only have a fragile understanding of verbs. Alternatively, in Chapter 2, I also discussed how 10-month-olds may have struggled to understand the verbs during the task as they may rely on additional supportive cues being in place to recognise familiar verbs during this early stage of linguistic development (e.g., lack of carrier phrases, verb framing, unfamiliar speaker). I also described how 10-month-olds may have struggled to abstract the correct referent when two action stimuli were presented side-by-side, as these simultaneous dynamic displays may have been too attentionally or cognitively demanding while also searching for a correct referent. As such, the looking while listening task used in Chapter 2 may not have been sensitive enough to accurately capture younger infants' verb knowledge. One useful approach to constrain the interpretation of absent target looking responses is by collecting converging physiological data that enable researchers to use a different technique to explore a common research question (Aslin, 2007). In the current chapter, I aim to shed light on findings from Chapter 2 by exploring 10-month-old infants' comprehension of verbs using an implicit neural measure of word understanding: the N400 event-related potential (ERP). In this task, infants saw single presentations of actions followed by auditorily presented verbs that either matched or mismatched the action, reducing attentional demands during the task.

3.1.1. N400 Event-Related Potential

A common physiological method of exploring cognitive processes in developmental populations are ERPs (Hoehl & Wahl, 2012). ERPs are derived from continuous electroencephalogram, which measures electrical activity at the scalp, by averaging together brain activity time-locked to stimulus events across many trials. Neural responses to different types of stimuli can then be compared to estimate whether infants discriminated between stimulus types. ERPs are a particularly advantageous physiological method to use with infant participants as EEG is non-invasive, has excellent temporal resolution, is less sensitive to motion artifacts (i.e., compared to methods such as fMRI), and can be used with awake infants (Haan & Thomas, 2002).

Many studies have used the N400 ERP component to measure language comprehension and linguistic processing in both adult and developmental populations (see Junge et al., 2021 and Kutas & Federmeier, 2011, for reviews). First reported by Kutas and Hillyard (1980), the N400 component describes a negative-going waveform in response to lexical-semantic violations that peaks around 400ms after word onset in centroparietal regions in adult participants (Kutas & Federmeier, 2011). It is important to note that the N400 specifically describes a waveform that is negatively deflected but not necessarily negative in absolute value (Kutas & Federmeier, 2011). One common task used to explore the N400 is known as the semantic-priming task. Semantic-priming tasks typically involve presenting participants with a meaningful stimulus (e.g., a picture, a word) followed by a word (either written or presented auditorily) that is congruent or incongruent with the previous semantic context. Averaged across trials, greater (i.e., more negative) amplitudes are associated with incongruent compared to congruent pairings. The meaningful prime stimulus presented at the beginning of a trial sets an expectation for the upcoming word. Therefore, the N400 is thought to reflect the degree of ease with which participants can integrate semantic information associated with a word, accessed from long term memory, with the prior semantic context (see Kutas & Federmeier, 2011; Lau et al., 2008, for reviews). Specifically, more negative amplitudes are thought to reflect additional effort whilst attempting to integrate a mismatching word with a prior context. Interestingly, the N400 is specific to semantic mismatches and is not sensitive to other types of linguistic violations (e.g., incorrect grammar) or unexpected events (Kutas & Federmeier, 2011). This is important as it demonstrates that the N400 component does not reflect a general response to words that are unexpected or statistically uncommon, but rather a specific response to violations of meaning. This makes the N400 response a useful measure of word understanding.

In infants, the N400 has primarily been used as an implicit measure of word comprehension (Junge et al., 2021; Kutas & Federmeier, 2011). Friedrich and Friederici (2004) were the first to observe the N400 effect in an infant sample. In this study, 19-month-old, German-hearing infants saw pictures of common objects followed by a noun that was either congruent or incongruent to the picture context. A more negative waveform to incongruent pairings than to congruent pairings was reported, providing evidence of neural mechanisms necessary to extract meaningful information from a word before infants reach the second year of life. It is important to note that infant ERP components often diverge from those of adults, with differing latencies, topography, polarities, and amplitudes that may be explained by neural maturation processes (de Haan, 2007). For example, infant ERPs typically have longer latencies, smaller amplitudes, and greater variability in ERP characteristics compared to their adult counterparts (Thierry, 2005). The infant N400 also has more variability in latency and distribution than the adult component, with effects that peak later than 400ms and a scalp distribution that is rarely localised to centroparietal regions. In a recent review, Junge and colleagues (2021) reported that infant N400 effects had been detected in windows that often start ~400ms post word onset but with offsets that start as early as 600ms and as late as 1200ms after word onset. The scalp distribution is similarly variable, with effects reported in central, parietal, as well as frontal regions (sometimes in varying combinations) with no consistent hemispheric localisation.

To date, the infant N400 has been used to explore a range of language topics (see Junge et al., 2021, for review), including measuring existing word knowledge (e.g., Friedrich & Friederici, 2004, 2005a, 2005b; Parise & Csibra, 2012), newly learned word-object associations (e.g., Friedrich & Friederici, 2011; Junge et al., 2012), sensitivity to mispronounced words (e.g., Duta et al., 2012; Mani et al., 2012), and exploring differences in word processing between typically developing infants and infants with an increased likelihood of language difficulties (e.g., Cantiani et al., 2017; Friedrich & Friederici, 2006).

3.1.2. Verb Stimuli and the N400

In adults, several studies have investigated the N400 response to verb stimuli. Many of these studies have focused on exploring whether verbs and nouns are processed by distinct neural structures (see Vigliocco et al., 2011, for a review), typically presenting participants with written verbs and nouns followed by a word of the same grammatical class that is either related or unrelated to the previous word (e.g., sweep-clean vs. sweep-stamp, newspaper-text vs. newspaper-merchant). The verb-N400 effect is largely similar to the noun-N400 effect, after controlling for semantic and sensory differences associated with word meanings (Barber et al., 2010; Vigliocco et al., 2006). For example, Barber and colleagues only used nouns and verbs that both referred to events (e.g., *the run* and *running*) and controlled for the type of sensations associated with the words (e.g., motor, sensory).

Whilst infants' verb understanding has not been studied via the N400, this component has been extensively studied in relation to infant noun understanding, using paradigms that primarily involve presenting infants with static images of objects followed by auditory nouns (e.g., Friedrich & Friederici, 2004, 2005b, 2005a, 2008, 2011; Junge et al., 2012; Parise & Csibra, 2012). Yet, to explore comprehension of more dynamic referents, such as understanding of action-verb links, video or live action stimuli are necessary to provide accurate referent exemplars. So far, video stimuli have been used to explore the N400 effect in relation to infants' understanding of action sequences (Kaduk et al., 2016; Monroy et al., 2019; Reid et al., 2009), gestures (Sheehan et al., 2007), and complex visual scenes (Helo et al., 2017). With adults, other studies have also explored the N400 response to verbs and nouns using video stimuli of models performing actions followed by auditory words. Molfese et al. (1996) presented adults with videos of actions being performed with an object (e.g., drinking from a cup) followed by an auditory verb or noun that either matched or mismatched with the video. The authors reported larger negative waveforms to mismatches compared to matches, for both word types, 350ms to 500ms after word onset[17]. This work demonstrates that mismatches between video stimuli and auditorily presented verbs can be used to explore the N400 effect, though this has not been directly tested with infant participants. I address this gap in the literature in the current study by presenting infants with videos of actions, followed by auditorily presented verbs.

3.1.3. Vocabulary Size and the N400

Several studies report that the N400 is linked with children's vocabulary size, with the N400 effect only detected in groups of infants and children with greater receptive (e.g., Junge et al., 2012) and productive vocabularies (Borgström et al., 2015a, 2015b; Friedrich & Friederici, 2010; Helo et al., 2017; Rämä et al., 2013; Torkildsen et al., 2008, 2009). In these studies, the N400 effect is typically explored with children grouped by their comprehensive or productive vocabulary size (i.e., low vocabulary size, high vocabulary size). For example, several of these studies found that only children with larger productive vocabularies showed an N400 effect for newly learnt word-object pairs (Torkildsen et al., 2008, 2009). Relatedly, one study with 12-month-olds only detected the N400 effect for known word-object pairs, as reported by caregivers, in infants with larger productive vocabularies (Friedrich & Friederici, 2010). Some researchers suggest that the failure to detect the N400 in infants with smaller

[17] The authors later replicated this paradigm with children aged 3- to 5-years-old, though focused on exploring other early ERP components (Tan & Molfese, 2009). Though the authors did not specifically explore the N400 in this study, they did demonstrate that this paradigm could be successfully used with developmental populations.

vocabularies possibly reflects slower developing lexical-semantic memories and that the N400 is not yet elicited for words that have fragile mental representations (Friedrich & Friederici, 2010). Whereas others speculate that infants with smaller vocabularies may be less familiar with words and therefore have reduced sensitivity to semantic priming (Junge et al., 2021).

3.2. The Current Study

In the present study, I used a video-verb matching paradigm to present infants with videos of actions followed by auditory verbs that either matched or mismatched the action to investigate 10-month-olds' verb comprehension. Specifically, I explored infants' neural response to mismatches to investigate whether 10-month-olds exhibited an N400 response to the same verbs and actions used in Chapter 2. By using this implicit measure of word comprehension, I aimed to extend the findings of the looking while listening paradigms in Chapter 2. During this study, two central hypotheses were tested:

Hypothesis 1: I predicted a N400 effect to incongruent, compared to congruent, action-verb pairings, which would suggest that 10-month-old infants comprehend the verbs in the task (i.e., the same 10 verbs tested in Chapter 2). That is, if 10-month-old infants understood the verbs in the task, then I would expect a greater negative waveform to incongruent, compared to congruent, action-verb trials. As the literature suggests that the N400 effect is not consistently detected in a particular brain region or hemisphere (Junge et al., 2021), especially in younger infants, I aimed to explore any potential interactions between condition and brain regions.

Hypothesis 2: As several studies have reported links between N400 amplitudes and children's vocabulary sizes. I predicted that the magnitude of the N400 effects (i.e., N400 amplitudes associated with incongruent trials subtracted from amplitudes associated with congruent trials) would be positively associated with infants' vocabulary sizes. I tested this with children's total parent-reported receptive and productive vocabulary. I also examined whether N400 effects would be associated with receptive verb vocabulary (for all verbs items and for verbs in the task) as one previous study has reported links between parent-reported word comprehension and N400 effects for items in the task (Friedrich & Friederici, 2010).

3.3. Method

The participants recruited for this study are the same infants that are described in Chapter 2, Study 2. The current ERP task and the eye-tracking, looking while listening task described in Chapter 2 applied different task-related exclusion criteria and, thus, included some different infants in analyses. As such, the **Participants** section (and associated demographics) described here somewhat vary from those in Chapter 2.

3.3.1. Ethical Approval

This study is associated with ethics application number EC.19.03.12.5595GRA3 and was approved by the Cardiff University School of Psychology Ethics Committee.

3.3.2. Participants

In total, 42 10-month-olds (24 female, M = 9.94 months, SD = 0.34, *range* = 9.44-10.6 months) were tested. Recruitment methods are described in Chapter 2. The current sample size was not derived from a formal power analysis, but rather, based on typical sample sizes reported in other infant N400 studies (see Junge et al., 2021, for a review). This sample size also aimed to account for 25-50% data loss that often occurs in infant ERP studies (Hoehl & Wahl, 2012; Stets et al., 2012). Several factors contribute to data loss in infant EEG studies including, but not limited to; EEG cap tolerance, excessive movement, fussiness, experiment being terminated early (e.g., infant starts crying, falls asleep), temperament, and inattentiveness (varying dependent on the type of stimuli used; Hoehl & Wahl, 2012; Marshall et al., 2009; Stets et al., 2012; van der Velde & Junge, 2020). Several infants were excluded from analyses due to not hearing English as a first language (n = 1), EEG cap refusal (n =1), or fussiness/excessive movement that resulted in insufficient data being contributed to each condition (n =13; see **3.3.5. EEG Data Acquisition and Processing** for details). All families received a small toy worth approximately £5, an "Infant Scientist" certificate, and a photograph of their infant wearing the EEG cap.

The final sample included 27 10-month-olds (16 female, M = 9.86 months, SD = 0.35, range = 9.44-10.6 months). All infants were monolingual, English-hearing infants (see Chapter 2 for monolingualism threshold details). All infants were born full term (i.e., 37 weeks or later) and had a typical birth weight (i.e., 5lb 9oz/2.52kg to 9lb 14oz/4.48kg)[18]. All

[18] One infant was reported has having a slightly lower birth weight. Infant was born full term and otherwise declared as healthy and typically developing.

infants were reported as typically developing and did not experience any developmental delays with vision, hearing, communication, or motor development. All families were living in South Wales. Infants were reported to be White-British (n = 24) or White-Asian (n = 3). Families were predominately middle class, with an average household income of £68,177 (SD = £30,537, *range* = £21,000-£160,000) before taxes. One parent completed up to GCSE education (3.7%), one parent received up to A Level qualifications (3.7%), 13 (48.1%) had Bachelor's degrees, nine (33.3%) had Master's degrees, and three (11.1%) had an M.D., P.h.D., or equivalent.

3.3.3. Materials

3.3.3.1 Stimuli

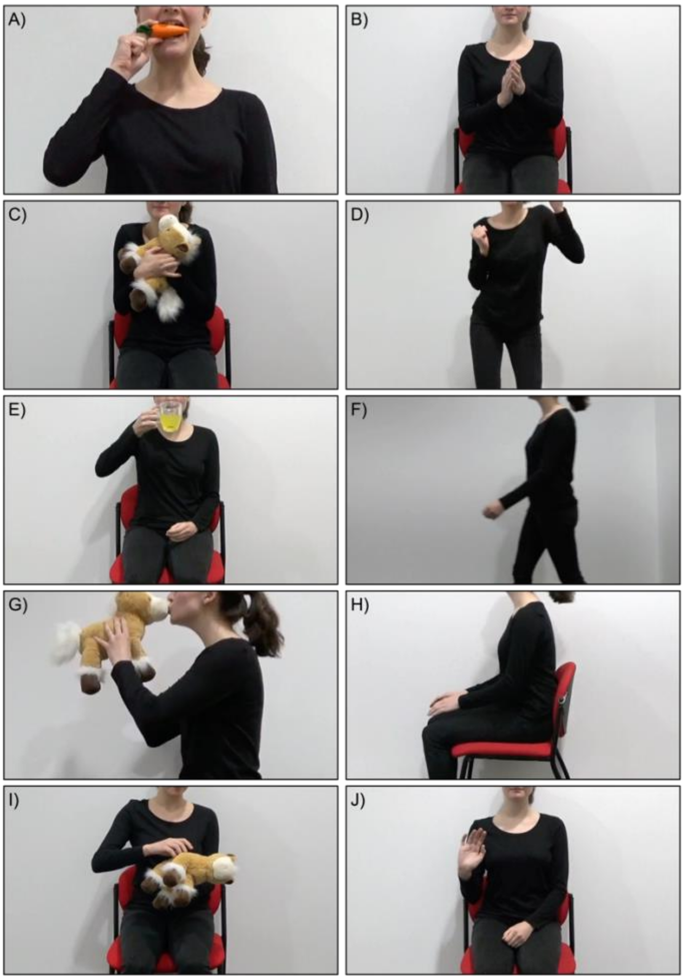
The same 10 verbs identified in Chapter 2 were used in this task: bite, clap, cuddle, dance, drink, kiss, sit, tickle, walk, wave (see **Figure 3.1**). These items were reported to be understood or spoken by at least 50% of infants aged 9- to 15-months-old in a survey. See Chapter 2 (**2.4.3.1 Stimuli Selection**) for full details regarding the stimuli selection. The same video and audio stimuli created for Chapter 2 were used in the ERP task. In this task, single videos of actions were presented paired with a verb that either matched or mismatched the action. This contrasts with Chapter 2 where videos were presented in yoked pairs.

3.3.3.2 Parent-Report Measures

The same parent-report measures described in Chapter 2 were used. Caregivers completed the UK-CDI (Alcock, Meints, et al., 2020) and EMQ (not analysed here; Libertus & Landa, 2013) to measure vocabulary and motor development. A family and demographics questionnaire was included. Questionnaires were completed after the experimental session via REDCap (Harris et al., 2009, 2019). See Chapter 2 (**2.4.3.3 Parent-Report Measures**) for full details.

Word comprehension scores were computed by summing the total number of words understood and the total number of words said, and production scores equal the total number of words said (total possible score of 395 for both comprehension and production). Comprehension scores for verb items in the UK-CDI are computed by summing the total number of verbs understood and the total number of verbs said (total possible score of 59). Comprehension scores for verb items from the task are computing how many verbs from the task are reported as understood (total possible score of 10). Verb production scores were not included in analyses as no infants in the sample were reported to say any verbs.

Figure 3.1
Still frames of video stimuli



Note: A still frame from each video stimulus. A) bite, B) clap, C) cuddle, D) dance, E) drink, F) walk, G) kiss, H) sit, I) tickle, and J) wave.

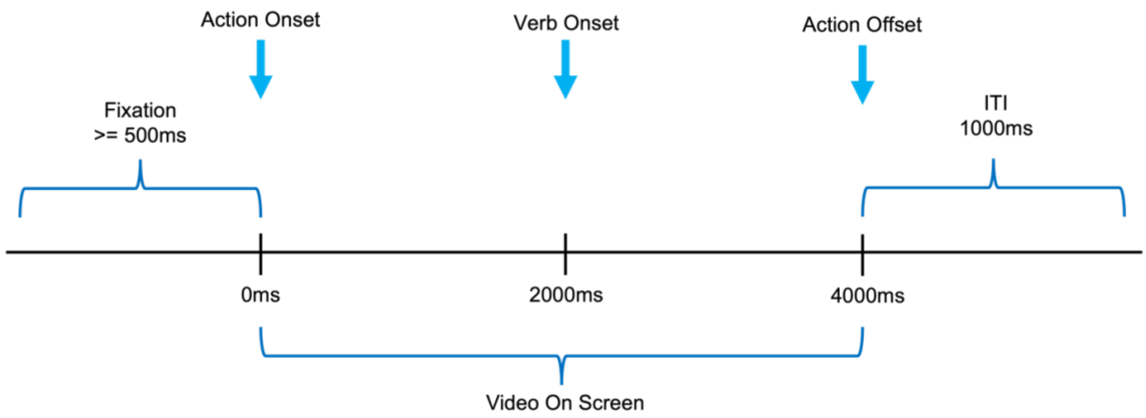
3.3.4. Procedure

Caregivers and infants were brought into the lab and made comfortable while the procedure was explained, and a second experimenter entertained the infant. Caregivers then provided written consent. The primary experimenter measured the infants' head circumference before adjusting the EEG cap onto the infants' head and applying electrode gel until sufficient impedance levels were achieved. During the task, infants were sat on their caregiver's lap in front of the screen inside the testing room. The second experimenter sat behind the family, just outside of the testing room, and would enter the room during breaks or periods of fussiness. Caregivers were asked to refrain from interacting with their child during stimuli presentation aside from reorienting their infant towards the screen or soothing them during periods of fussiness. The session was video recorded via a live feed webcam, on top of the monitor, that enabled the experimenter to monitor infant attentiveness and fussiness. Prior to the ERP task, infants completed the eye-tracking, looking while listening task described in Chapter 2 that lasted approximately 5 minutes. Families took a short break, lasting approximately 5 minutes, to play with toys and have a snack/feed in-between the tasks.

During the task, infants were presented with videos of actions paired with pre-recorded congruent or incongruent verbs, while their EEG was continuously recorded. Stimuli were presented with E-Prime 3.0 software (Psychology Software Tools, 2016) on a movable 23" monitor (1920 x 1080 pixels) that could be flexibility adjusted to infants' height (to align the centre of the screen with infants' eye line) and distance from the screen (adjusted to approximately 60-65cm). Audio stimuli were played from the monitor speakers. Prior to each trial, infants' saw a fixation cross for a minimum of 500ms. The primary experimenter monitored the infant, via the video feed, and instigated the trial when the infant oriented to the centre of the screen. During the fixation period, should the infant not orient to the screen, the experimenter presented a brief attention-grabbing video (e.g., a shaking toy duck accompanied with tinkling bells) until they looked at the centre of the screen. Each trial consisted of a video being presented for 4000ms (see **Figure 3.2** for trial timeline). As with previous studies using video stimuli paired with matching or mismatching verbs (Molfese et al., 1996; Tan & Molfese, 2009), the verb stimulus was presented while the video was still on screen, 2000ms after video onset. All the actions, and goals associated with the actions, were recognisable by at least 2000ms. The verb audio ranged from 660ms to 1030ms in length. The inter-trial interval (ITI) was 1000ms.

There were 200 trials in total, 100 congruent and 100 incongruent. Congruent (i.e., the "dance" action paired with the verb "dance") and incongruent (e.g., the "dance" action paired with the verb "bite") trials were equally divided across verb items. For example, the "wave" action video was seen 20 times; 10 of those trials were followed by a congruent verb (i.e., "wave!") and the other 10 trials were followed by an incongruent verb (e.g., "dance!"). The incongruent action-verb pairings varied across trials using other verbs in the stimuli set to prevent potential learning effects. Each verb item served as an incongruent verb an equal number of times across the experiment. Congruent and incongruent trials for each action were equally divided across the first and second half of the experiment. Two pseudorandom counterbalanced trial orders were constructed. These orders were constructed to certify that an action or verb token did not repeat in consecutive trials and that each trial type (congruent and incongruent) did not appear more than twice in a row. The task lasted approximately 20 minutes. Testing continued until all trials had been completed or until infants' attention could no longer be maintained. After the session, caregivers were sent a URL link to complete the demographic questionnaire, UK-CDI, and EMQ.

Figure 3.2
Schematic of the trial sequence



3.3.5. EEG Data Acquisition and Processing

Continuous EEG was recorded with BrainVision Recorder and the actiCHamp Plus system (Brain Products GmbH, Gilching, Germany). EEG was recorded from 32 channels, using an actiCAP electrode cap (Brain Products GmbH, Gilching, Germany), with active electrodes arranged according to the International 10-20 system (Fp1, Fp2, F7, F3, Fz, F4, F8, FT9, FC5, FC1, FC2, FC6, FT10, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, O1, Oz, O2). To improve conductivity, electro-gel was applied, and impedances were mostly kept below or at 50kΩ. During recording, activity was sampled at a rate of 500Hz and the data were referenced to Cz. The ground electrode was placed over Fpz.

EEG data were pre-processed offline in MATLAB. The data were first video coded for visual attendance based on time-locked, video recordings. Trials where infants did not attend to the video and/or likely did not hear the verb (e.g., due to the infant verbalising or caregiver speaking during the verb) were excluded (see **Table 3.1** for trial loss descriptives). Data were band-pass filtered at 0.3-30Hz (in alignment with developmental N400 studies; Paul & Mani, 2022) and re-referenced using an average reference of all electrodes. The EEG was segmented into epochs from 200ms before verb onset to 1200ms after verb onset, in line with epochs typically used in developmental N400 studies (Paul & Mani, 2022). Automatic artifact identification and rejection was applied with trials containing artifacts -/+200µV. Extracted epochs were baseline-corrected using the mean voltage from across the 200ms period prior to verb onset. Mean amplitudes were scored for each electrode in frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal regions (P3, Pz, P4). Electrode positions were selected in line with current N400 recommendations (Šoškić et al., 2021). Mean amplitudes were included in analyses as they are reported to be more robust (i.e., less influenced by noise) compared to peak amplitudes (Clayson et al., 2013). The mean amplitude was calculated within a time window ranging from 400 to 700ms post verb onset. The time window selected was based on prior infant N400 literature and visual inspection of the N400 grand mean plot. Specifically, the 400ms onset time was selected to align with infant N400 studies, which is relatively consistent across studies (Junge et al., 2021), and confirmed with visual inspection. In contrast, the offset time is more variable across studies (Junge et al., 2021) and was selected here using visual inspection and confirmed to overlap with timing used in studies using dynamic visual stimuli (Helo et al., 2017; Sheehan et al., 2007). Infants were required to contribute at least 10 artifact-free trials, per condition (congruent verb | incongruent verb), to be included in analyses. As can be seen in **Table 3.1**, on average, infants completed more incongruent than congruent verb trials. At the same time, they also lost more incongruent compared to congruent trials due to motion artifacts. There were no differences in the number of artifact-free trials included in each condition. Infants equally attended to both trial types.

Table 3.1

Final Sample Trial Attrition Descriptives, by Condition

	Congruent Verb		Incongruent Verb			
	M	*SD*	*M*	*SD*	*t*	*p*
Total Trials Completed	41.37	10.88	43.22	10.50	-4.53	<.001
N of Artifact-Free Trials	25.15	9.96	26.37	10.54	-1.87	.073
N of Trials Lost to Artifact	6.33	3.19	8.00	3.93	-2.79	.010
N of Trials Lost to Inattention	9.89	4.99	8.85	5.01	1.47	.154

3.4. Results

All analyses were performed using R Statistical Software (R Core Team, 2020). Within R, data manipulation and plots were completed with the *Tidyverse* packages (Wickham et al., 2019). Specific analysis packages are described alongside test results. Across analyses, statistical significance was assessed at an α of .05. The materials, data, and analysis script are available at https://osf.io/mbn94/?view_only=8f9e3fd67e3d4fc5a7eb562626229b12

3.4.1. Congruent versus Incongruent Verbs

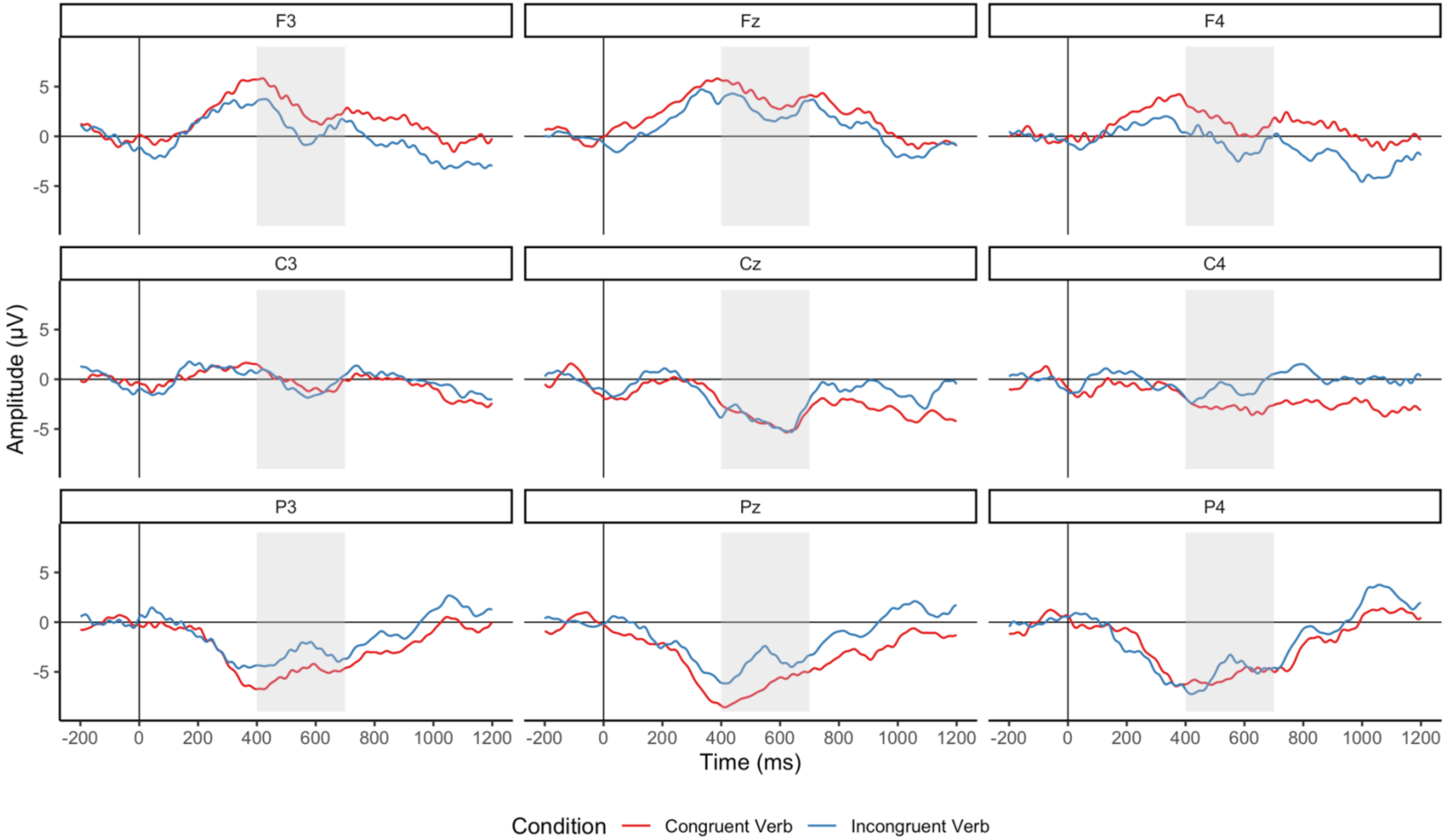
Visual inspections of mean amplitudes (grouped by condition, region, and hemisphere) using histograms showed broadly normal distributions. As such, a repeated measures analysis of variance (ANOVA) was used to assess differences between the congruent verb and incongruent verb conditions using the *aov_car()* function in the *afex* package (Singmann et al., 2021). The *aov_car()* function automatically applied the Greenhouse-Geisser correction when non-sphericity was detected. Main effects and interactions were followed up using *emmeans()* and *pairs()* from the *emmeans* package (Lenth, 2021). During follow-up analyses for interactions and main effects, the Bonferroni correction was applied to correct for multiple comparisons. This correction was applied by adjusting the *p*-values (which are seen in the main text) rather than adjusting the α criterion.

Aligned with previous literature (Junge et al., 2021), preliminary analyses revealed no effect of hemisphere (see **Appendix E**), therefore, mean amplitude was averaged across left, midline, and right hemispheric regions. Thus, to explore whether there was a difference in mean amplitude between the congruent and incongruent verb conditions, a two-way repeated measures ANOVA was conducted with condition (congruent verb | incongruent verb) and region (frontal | central | parietal) as within-subject factors. The ERPs for both congruent and incongruent trials are show in **Figure 3.3**. The analysis revealed a significant main effect of brain region, $F(1.57, 40.71) = 17.66$, $p < .001$, $\eta_p^2 = .40$. Follow-up tests revealed that, across conditions, frontal mean amplitudes were significantly greater than those in the central (*Mdiff* = -4.55, $t(52) = -3.93$, $p < .001$) and parietal regions (*Mdiff* = -6.75, $t(52) = -5.83$ $p < .001$). The main effect of condition was not significant.

There was also a near significant condition by region interaction, $F(1.85, 48.18) = 3.22$, $p = .052$, $\eta_p^2 = .11$. As I aimed to explore any potential interactions with condition, I conducted follow up tests to explore this marginal interaction further. In the frontal region only, incongruent verbs evoked amplitudes that were significantly more negative than for congruent verbs (see **Figure 3.4**; *Mdiff* = 1.67, $t(76.5) = 2.05$, $p = .044$). No differences in amplitude between incongruent or incongruent trials were detected in central (*Mdiff* = -0.73, $t(76.5) = -0.89$, $p = .377$) or parietal regions (*Mdiff* = -0.75, $t(76.5) = -0.92$, $p = .359$).

Figure 3.3

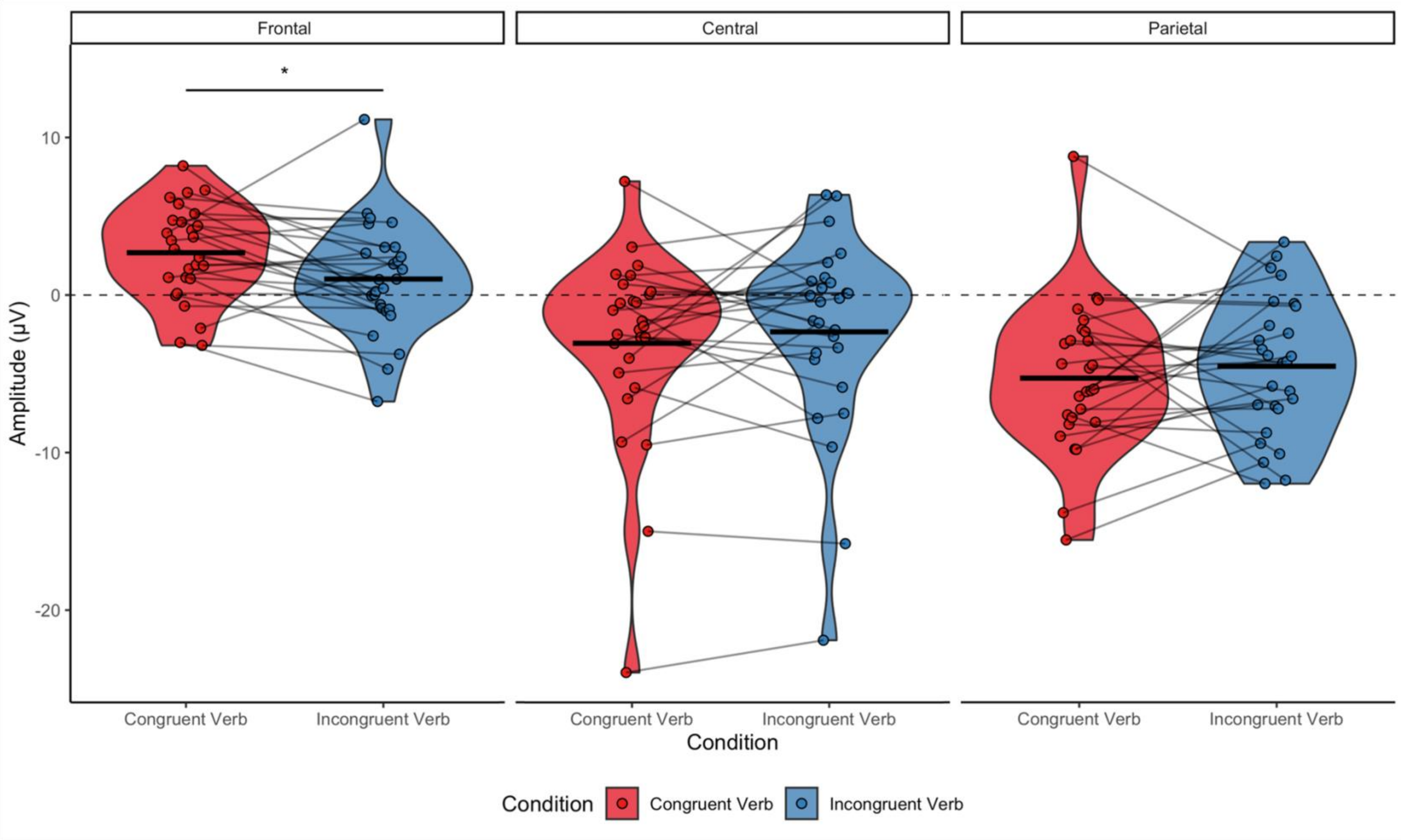
ERPs for congruent and incongruent verbs



Note: The ERPs to congruous and incongruous verbs in frontal, central, and parietal electrodes. Red lines represent congruent verbs and blue lines represent incongruent verbs. The grey box represents the time window of analysis for the N400 component (400-700ms). Negative is plotted down.

Figure 3.4

Mean N400 amplitudes by condition and region



Note: A violin plot showing the means and distributions of N400 amplitudes, by condition, averaged across region. Individual infant amplitudes across conditions are linked with black lines. Black horizontal lines represent the mean amplitude.

3.4.2. Vocabulary Analyses

3.4.2.1 CDI Descriptives

Table 3.2
Vocabulary Descriptive Statistics

CDI Score	*M*	*SD*	*Min*	*Max*
All Words - Comprehends	58.44	44.16	0	149
All Words - Says	2.56	3.66	0	16
All Verbs - Comprehends	9.3	8.7	0	26
Task Verbs - Comprehends	4	3.13	0	10

Note: CDI: UK Communicative Development Inventory. CDI scores refer to the number of words reported to be understood or said. Comprehension and production scores are reported for all items in the measure, verb items in the measure, and verb items from the task. No infants were reported to say any verbs (from the CDI or from the task) and, therefore, no values are reported.

3.4.2.2 Associations Between N400 Amplitudes and Vocabulary Scores

To assess correlations between the magnitude of the N400 effect and parent-reported vocabulary, the *cor_test()* function from the *rstatix* package was used (Kassambara, 2021). To compute the magnitude of the N400 effect, the mean amplitude was averaged across the frontal region, based on the aforementioned analysis only detecting effects in this region, and calculated by taking the mean amplitude associated with incongruent verbs from the mean amplitude associated with congruent verbs. With this difference score, larger values indicate a larger N400 effect. Specifically, I correlated the magnitude of the N400 effect with children's total CDI comprehension score and total CDI production score. Additional analyses also explored links between comprehension score for all CDI verb items and comprehension score for verb items included in the task to investigate whether infants' N400 response is specifically related to their verb knowledge. No infant was reported to say any verbs and, thus, verb production scores were not explored. Visual inspections of distributions, via histograms, revealed largely normal distributions for N400 amplitudes but non-normal distributions for vocabulary scores. Therefore, Spearman's non-parametric correlations were applied. All tests were one-tailed (see **Hypothesis 2**). A positive association approaching significance was found between the number of words infants were reported to say overall and the magnitude of their N400 response (see **Table 3.3**). No other significant or marginal correlations between N400 amplitudes and vocabulary scores emerged.

I also conducted additional exploratory analyses to investigate the links between the N400 effect and infants' vocabulary development, aligned with previous studies (e.g., Borgström et al., 2015a, 2015b; Friedrich & Friederici, 2010; Helo et al., 2017; Rämä et al., 2013; Torkildsen et al., 2008, 2009). Specifically, in these studies, children were grouped by either their overall CDI comprehension score (i.e., the number of words they are reported to understand) or their overall CDI production score (i.e., the number of words they are reported to say) by using a median split approach before exploring the N400 effect. Aligned with this approach, I conducted two ANOVAs with the same structure as described in **3.4.1** but included vocabulary score (low | high) as an additional between subjects factor. The first ANOVA split infants based on their overall comprehension score and the second split infants based on their overall production score. Infants with vocabulary scores that equalled the median score were assigned to the "low" group as this resulted in more evenly balanced groups. For comprehension scores, 51 words understood was the median value (see **Table 3.2** for standard deviation and range); 14 infants were classified as having lower vocabulary scores and 13 infants were classified as having higher vocabulary scores. In contrast, for production scores, 1 word said was the median value (see **Table 3.2** for standard deviation and range); 15 infants were classified as having lower vocabulary scores and 12 infants were classified as having higher vocabulary scores. For both models, there were no main effects or interactions with vocabulary. The remaining results of the analysis remained highly similar to those described in **3.4.1** (see **Appendix F**).

Table 3.3
Correlation Table Between Magnitude of N400 Effect and Vocabulary Scores

Vocabulary Score	r_s	p
All Words - Says	.32	.054
All Words - Comprehends	.20	.153
All Verbs - Comprehends	.16	.219
Task Verbs - Comprehends	.18	.186

3.5. Discussion

The aim of the current study was to investigate an electrophysiological measure of word understanding – the N400 component – to explore whether there is neural evidence that by 10-months-old, infants comprehend verbs. Infants were presented with videos of everyday actions being performed by an adult model, followed by an auditory verb that either matched or mismatched the action. Here, an N400 effect was observed in frontal regions during a 400-

700ms window, with more negative amplitudes found to incongruent action-verb pairs than congruent pairs. These results provide physiological evidence that by 10-months-old infants can integrate verb meanings with meaningful action exemplars, suggesting that infants already understand several early verbs by this age. However, it is important to note that as the interaction between condition and brain region was only marginally significant, these findings should be interpreted with caution. A marginal association was also found between the magnitude of the N400 effect and the total number of words infants were reported as able to say. No other associations were found between the N400 effect and parent-reported word comprehension or production. In the following section, I begin by discussing how these neural-level findings provide important insight into when infants' evidence the ability to link verbs with actions and recognise verbs as referential in nature. I then discuss associations between infants' vocabulary development and N400 effect before considering the characteristics of the N400 response detected in the current study.

As described in Chapters 1 and 2, previous looking while listening studies have reported that by 10-months-old, infants can already understand some early abstract words and phrases (Bergelson & Swingley, 2013; Nomikou et al., 2019). Yet, in Chapter 2, 10-month-olds failed to link verbs with target actions in two looking while listening tasks. I previously described how these findings could suggest that 10-month-olds did not recognise the verbs in the task as they are still at an early stage of linguistic and cognitive development. I also discussed some alternative methodological explanations for 10-month-olds failure to comprehend the verb items during the looking task. For example, 10-month-olds verb recognition could depend on additional supportive cues being present to recognise verbs when they are spoken, such as the use of function words (e.g., "*She is* dancing"; de Carvalho et al., 2019), verb framing (e.g., "It's ___ing!"; He & Lidz, 2017), or verb tokens being spoken by a familiar speaker (e.g., Bergelson & Swingley, 2018). The current findings shed light on Chapter 2's results by providing neural-level evidence that 10-month-olds can successfully link familiar verbs with action exemplars, even in the absence of supportive cues. Importantly, elicitation of the N400 effect is often considered as evidence of "genuine words" in developmental populations (i.e., that infants have formed a referential link between a word and semantic concept) contrasted to "proto words" which describe basic associations between sound patterns and early categories that looking time tasks sometimes capture (Friedrich, 2017; Nazzi & Bertoncini, 2003). That is to say, the presence of the N400 offers physiological evidence that infants understood the meaning of the verbs used in the task. Interestingly, in the current design, infants saw the same actions and heard the same pre-recorded verbs as in Chapter 2. Indeed, these were also primarily the same infants who took part in Chapter 2's eyetracking looking while listening task. As such, it is unlikely that infants failed to look at target items in Chapter 2's looking task because they failed to extend familiar verbs to the specific stimuli used in the task, have difficulty linking verbs with actions, struggled to understand an unfamiliar speaker, or because of absent function words and verb framing. Rather, as previously described, it is possible that infants found the looking while listening task too cognitively demanding (e.g., Pruden et al., 2012) or that their looking behaviour was, in part, influenced by visual preference (Aslin, 2007). It is possible that the reason an effect was detected in this task, but not in the looking while listening task, is that infants included in the current sample (which has different data exclusion criteria than Chapter 2) had, on average, more advanced language skills than those in Chapter 2. However, this may be unlikely given the similarity in parent-reported CDI comprehension and production scores in both samples.

It is important to note, that the current results do not imply that 10-month-olds easily acquire verbs or possess a substantial verb lexicon. Indeed, a large body of research clearly demonstrates that children struggle to acquire verbs in day-to-day life and lab settings, compared to concrete nouns (Bornstein et al., 2004; Caselli et al., 1995; Childers & Tomasello, 2002; Forbes & Farrar, 1995; Gentner, 1978, 1982; Gentner & Boroditsky, 2001; Imai et al., 2005, 2006, 2008; Jackson-Maldonado et al., 1993; Kersten & Smith, 2002). Rather, these findings show that 10-month-olds infants have begun overcoming initial verb-action mapping dilemmas, alongside other social-cognitive developments such as speech perception (Werker & Hensch, 2015), broader language acquisition (Bergelson & Swingley, 2012, 2013), gaze following (Brooks & Meltzoff, 2005), and event processing (Baldwin et al., 2001; Pruden et al., 2012; Pulverman et al., 2008, 2013). Broadly, these findings have important implications for theories of language development, highlighting *when* infants can first link verbs with action concepts and recognise verbs as referential words. In Chapter 1, I outlined several theories describing mechanisms through which children might learn verbs (e.g., innate biases, social pragmatics, associative learning, syntactic bootstrapping). Though the current findings provide little insight into whether 10-month-olds use such mechanisms to grasp the meaning of their first verbs, it lays important groundwork for future research to test these word learning mechanisms with younger age ranges.

Partially aligning with previous work (Borgström et al., 2015a, 2015b; Friedrich & Friederici, 2010; Helo et al., 2017; Rämä et al., 2013; Torkildsen et al., 2008, 2009), a marginally significantly association was found between the N400 effect and the number of words infants are reported to say. That is, that the number of words infants were reported to say was associated with the difference in mean amplitude in response to congruent compared to incongruent verbs, with more words produced linked with a greater difference in amplitude. This marginal correlation may possibly suggest that infants with larger vocabularies and greater language skills more easily form stronger lexical-semantic links between verbs and actions than infants with small vocabularies (Friedrich & Friederici, 2010). However, this finding should be interpreted with caution given that the correlation was marginal and no other links with vocabulary emerged. Further, it is possible that the failure to find any associations between word comprehension (for all words and verbs) may be, in part, explained by how caregivers understandably often rely on word production as an indicator of word understanding.

Finally, in adults, the N400 effect is typically greatest over centroparietal regions, peaking around 400ms (Kutas & Federmeier, 2011), and most frequently detected in windows between 300 and 500ms after word onset (Šoškić et al., 2021). Yet, in the present study, greater N400 amplitudes were detected in frontal regions only. There was no evidence of hemisphere localisation, which is not uncommon in infant N400 studies (Junge et al., 2021). Junge et al.'s (2021) recent review highlighted that the infant N400 can be detected in a wide range of windows. Though effects are usually detected in windows starting at 400ms post word onset, the N400 offset can vary between 600ms and 1200ms after stimulus onset across the first two years of life. That said, many of the studies reviewed by Junge and colleagues utilised a window offset between 600 to 800ms after word onset, including those using dynamic stimuli (Helo et al., 2017; Sheehan et al., 2007). Broadly aligned with these studies, the current study applied a 400ms onset time and 700ms offset time. Like adult studies, many infant N400 studies also report effects in parietal as well as central and/or frontal regions (Junge et al., 2021). In the current study, no N400 effect was detected in centroparietal recording sites, while it was only found in frontal sites. Interestingly, the first studies to explore the infant N400 also reported strong effects in frontal regions, that have been interpreted to represent semantic processing that is specific to visual stimuli (Friedrich & Friederici, 2004, 2005a). Further, frontal effects are often reported in N400 studies using video (e.g., Helo et al., 2017) or dynamic stimuli, such as actions or gestures being performed (e.g., Reid et al., 2009; Sheehan et al., 2007). This frontal distribution is thought to, in part, be explained by the simultaneous activation of motor and pre-motor regions while observing actions (Amoruso et al., 2013). As such, the frontal scalp distribution detected here is likely explained by the use of action-based, video stimuli.

3.6. Conclusion

In Chapter 2, 10-month-olds failed to demonstrate comprehension during the looking while listening tasks, beyond a small number of items. Possibly, the looking while listening paradigms used in Chapter 2 may have been attentionally demanding for younger infants and may have been influenced by visual stimulus preference. As such, infants' failure to look at the target actions in those tasks was challenging to interpret. Here, I extend these findings by investigating verb comprehension via implicit, neural correlates of word comprehension in a sample of 10-month-old infants. These findings show that 10-month-old infants link verbs with action exemplars, evidenced by an N400 component effect, shedding light on Chapter 2's findings and broadening current understandings of infants' word learning capabilities which has implications for theories of verb and word learning.

Chapter 4. Parent Reported Relations Between Vocabulary and Motor Development in Early Childhood: Differences Between Verbs and Nouns

4.1. Introduction

In Chapters 2 and 3, looking time paradigms and neural measures of word comprehension were used to examine infants' understanding of verbs. The current chapter is motivated by previous literature showing that the acquisition of motor skills appear to facilitate language acquisition in typically developing infants. In Chapter 1, I briefly described several of these studies reporting links between children's motor development and their vocabulary acquisition (e.g., Alcock & Krawczyk, 2010; He et al., 2015; Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012, 2016; Ruddy & Bornstein, 1982; Walle & Campos, 2014). These findings align with embodied accounts of language development that suggest gains in motor skills provide infants with novel opportunities to explore environments, interact with objects, and engage in new social interactions with caregivers that, in turn, may facilitate language acquisition (Iverson, 2010, 2021, 2022; Oakes & Rakison, 2020; Piaget, 1952; Thelen, 2000a, 2000b; Thelen & Smith, 1996). The present study aims to extend this literature by investigating whether infants' motor capabilities may be differentially associated with comprehension of specific word classes, namely, of verbs and nouns.

4.1.1. Motor Development and Vocabulary Acquisition

Within this literature, parent-report measures of infants' motor skills and vocabulary size, investigated concurrently or longitudinally (see Gonzalez et al., 2019, for a review with typically developing children) have been used to explore links between these domains. These studies consistently report links between typically developing infants' motor development and vocabulary size, with greater motor skill abilities being associated with both concurrently and longitudinally larger vocabularies. In this section, I describe several correlational studies reporting links between infants' motor and language development, supported by research that has also explored how motor gains change infants' day-to-day physical, perceptual, social, and linguistic experiences.

Studies using parent-report measures of motor scores and vocabulary development report general positive associations between gross motor skills and the number of words infants understand and say (Alcock & Krawczyk, 2010; Valla et al., 2020). Gross motor skills refer to actions that rely on large muscles in the arms, legs, and torso to make large limb movements. The acquisition of gross motor skills is thought to effect meaningful changes in infants' linguistic and communicative development as abilities such as independent sitting and self-locomotion emerge. For example, unaided sitting improves infants' visual access to their surroundings and ability to grasp and explore objects, resulting in increased caregiver interactions (Franchak et al., 2018; Kretch et al., 2014; Rochat & Goubet, 1995; Soska & Adolph, 2014). Indeed, infants that learn to sit unaided earlier in infancy have larger productive vocabularies as they approach toddlerhood (Oudgenoeg-Paz et al., 2012). Similarly, the transition from crawling to walking affords infants visual and hands-free access to distal locations, objects, and people (Dosso & Boudreau, 2014; Karasik et al., 2011). This transition is marked by increased communication from caregivers as infants engage in more complex social bids (Clearfield, 2011; Clearfield et al., 2008; Karasik et al., 2014; Schneider & Iverson, 2022). During this time, infants also begin producing more gestures and vocalisations, which caregivers of early walkers increasingly respond to (West & Iverson, 2021). Walking infants also tend to understand and say more words than crawling infants of the same age (He et al., 2015; Walle & Campos, 2014, but see, Moore et al., 2019) and understand more words later in development than infants who start walking later too (Oudgenoeg-Paz et al., 2012). In sum, gross motor skills seemingly afford infants with enhanced postural positioning and self-locomotion capabilities that enhance their visual experience of the environment and provide new opportunities to explore and receive social attention from their caregivers. This, in turn, may explain why they tend to have larger vocabularies.

Relatedly, advances in fine motor abilities are also associated with larger receptive and expressive vocabularies during infancy (Alcock & Krawczyk, 2010; Houwen et al., 2016). Fine motor skills are typically defined as hand movements and actions that require precise coordination, such as grasping and object manipulation, and are considered as distinguishable from communicative gestures (Alcock & Krawczyk, 2010). The ability to manipulate objects with precise movements facilitates infants' acquisition of object knowledge, increasing familiarity with different object properties such as shape, complexity, texture, and weight (Rochat, 1989; Ruff, 1984). In moments of referent labelling, fine motor skills enable infants to hold and manipulate objects which occupy their visual field and, thus, focus their attention on the referent (i.e., "embodied attention"; Pereira et al., 2014; Yu & Smith, 2012). Indeed, 4- and 6-month-old infants skilled at manipulating and exploring objects typically have larger vocabularies later during infancy and toddlerhood than infants who are less skilled at object manipulation at these ages (Choi et al., 2018; Ruddy &

Bornstein, 1982; Zuccarini et al., 2018). Infants are also more likely to know the label for an object if they have experience manipulating it (Suarez-Rivera et al., 2022) and caregivers increasingly respond to fine motor actions by producing verbs as infants become older (West et al., 2022). Thus, precise hand movements enable infants to learn about objects, perform new actions with objects, and engage in multi-modal language learning supported by caregivers responding with labels at "the right moment" (Pereira et al., 2014; Schroer & Yu, 2022; Yu & Smith, 2012).

Further evidence of associations between motor and language acquisition during early development comes from research with children that often experience communicative or motoric delays such as those with a diagnosis of autism spectrum disorder (ASD), specific language impairment (SLI), Down syndrome, Williams syndrome, fragile X syndrome, and developmental coordination disorder (DCD; see D'souza et al., 2017 and Leonard & Hill, 2014, for overviews). Notably, much of this research has been conducted with child, rather than infant, samples due to diagnosis for most conditions only occurring in toddlerhood or childhood. As an alternative, some studies have recruited infants with an increased likelihood of experiencing a condition, such as siblings of children with a diagnosis. For example, autistic children or infants with a heightened likelihood of ASD are more likely to experience gross and fine motor delays than typically developing infants, which has been linked with reduced object exploration and language delays (Jarvis et al., 2020; West, 2019; West et al., 2019). SLI is a communication condition, characterised by language difficulties than cannot be explained by other developmental or hearing delays. Motor difficulties are often present for children with SLI, and these have been linked with delays in word comprehension and verbal skills (see Leonard & Hill, 2014, for a review). Similarly, children with Down syndrome often experience decreased muscle tone, hypermobility, and delayed motor skill onsets (Ulrich & Ulrich, 1993) which are proposed to have cascading impacts on cognitive development, including difficulties with expressive language (D'Souza et al., 2017). Knowledge and awareness of interconnections across these domains not only broaden our understanding of how and why children with developmental conditions may experience language delays (D'Souza et al., 2017), but also open pathways for screening and intervention (Leonard & Hill, 2014).

4.1.2. Verb Learning and Motor Development

Whilst typical motor development alone is neither "necessary nor sufficient" for language and communication skills to occur (Iverson, 2010), this body of literature suggests that emergent motor capabilities may have cascading effects on the development of language (Iverson, 2022). Interestingly, much of this research has focused on children's overall language outcomes by measuring parent-reported vocabulary size. Though this broadens our understanding of the cascading impacts motor skills may have on general linguistic development, it is unclear how or whether motoric gains may better support specific aspects of word learning. As I outlined in Chapter 1, verbs and other relational terms present as a particularly difficult challenge for children. Unlike nouns, relational words are abstract in nature and describe ephemeral referents that are challenging to visually extract from the environment (Gentner, 1978; Gentner & Boroditsky, 2001). How is it then that children learn verbs? One possible source of support for learning verbs could be children's own actions afforded to them by motor skill attainment.

In Chapter 1, I outlined several theoretical explanations for verb learning (e.g., cognitive biases, social pragmatic skills, syntactic bootstrapping, associative learning). Many of these perspectives describe how the challenge of early verb – or word – learning attributed to referential uncertainty is reduced through the use of powerful social and/or cognitive mechanisms. For example, the constraints approach to word learning assumes that children use cognitive biases to pare down the number of word-referent hypotheses, such as assuming novel words refer to objects or actions that they do not currently have a label for (e.g., Golinkoff et al., 1995; Markman, 1990). Other approaches hypothesise that infants learn the meaning of novel verbs by discerning the referential intent of a speaker's actions (Akhtar & Tomasello, 2000; Tomasello, 1995) or by using syntactic cues available within speech (Gleitman, 1990; Naigles, 1990). In contrast, associative word learning approaches suggest that children use powerful domain-general statistical learning mechanisms across multiple exposures to notice links between words and referents (Samuelson & Smith, 1998; Smith et al., 1996; Yu & Smith, 2007). Most of the above theories would not directly predict that children's actions and motor development support the acquisition of verbs or other words. However, recent work exploring statistical word learning during infancy and toddlerhood has demonstrated that associative noun learning can be further bolstered by children's own actions while learning new nouns (McQuillan et al., 2020; Pereira et al., 2014; Yu & Smith, 2012). Within these studies, children are given the opportunity to play with novel objects with their parents, while both parties wear head-mounted cameras and their parents have learned the novel names for these objects. After playing with the objects together, infants' novel word learning for these objects names is tested using a looking time task and infants' visual experience during the object play is explored. Across these studies, it was reported that infants best learned the names for objects that were associated with frequent co-occurrences of parent utterances and infant object holding resulting in the visual field being dominated by the referent. That is, infants' own actions of bringing objects closer to their faces and aligning their head positioning to look at the object, paired with parental labelling, was linked with word learning. In sum, infants' actions seem to support their novel noun learning, in at least some cases.

Though not yet tested with verb learning, it is possible that gains in motor skills, which afford infants the ability to perform new actions, may also support verb learning. For example, children's earliest verbs typically first describe actions that children are able perform with their bodies (Maouene et al., 2008, 2011) and studies show that 2-and 3-year-old children may exploit motoric experiences to understand the meaning of a novel verb (Gampe et al., 2016). Further, several studies show that as infants engage in actions, caregivers frequently respond with verbs that temporally align with infants' actions (Nomikou et al., 2017; West et al., 2022) and describe the type of action being performed (Tamis-LeMonda et al., 2019; West et al., 2022). Oudgenoeg-Paz and colleagues (2015) also provide evidence that infants' motor development may play a role in relational word learning. In this study, children's motor development at 20-months-old was found to predict their understanding of relational words (e.g., prepositions) at 36-months-old, suggesting that motor skills may bolster relational word learning. As such, verb learning may best occur in moments of co-ordination between infants' bodily actions and labelling events, suggesting that motor development may, in part, support children's verb learning. Indeed, it is possible that motor development may be especially important for verb learning given that verbs are proposed to be grounded in sensorimotor experiences (Barsalou, 2008; Glenberg & Gallese, 2012). Here, in line with embodied perspectives of word learning, I hypothesise that motor skills may be especially important for verb, over noun, acquisition. I propose that verb acquisition may be tightly tied with motor development given that infants' sensorimotor experiences support the processing of actions and increase verb labelling from caregivers which, in turn, may support the interpretation of new verbs. It is important to note that motor skills undoubtably also support noun learning, particularly in moments of "embodied attention" by producing opportunities for infants to engage with new objects that caregivers go on to label (Pereira et al., 2014; Schroer & Yu, 2022; Suarez-Rivera et al., 2022; Yu & Smith, 2012). Yet, early noun referents are typically concrete objects that are easier to identify and conceptualise than verbs. In contrast, learning verbs is far more challenging due to the abstract nature of verb referents and gains in motor skills may help children overcome these verb learning dilemmas. For example, infants' own actions not only help them to better understand actions (Gerson & Woodward, 2014a) and the components of an action that are lexicalised in a verb (Sootsman Buresh et al., 2006), but they also create essential moments for caregivers to directly label verbs "in action" (West et al., 2022). Yet, whether cascading benefits of motor skill acquisition are more tightly related to infants' understanding of verbs over nouns is unknown. This is because previous work has not directly tested whether verb acquisition is associated with motor development or explored whether this relation differs in strength to that with noun acquisition.

4.2. The Current Study

To test whether infants' motor abilities were differentially associated with concurrent verb and noun comprehension, I asked caregivers of infants aged between 6- and 24-months-old to complete parent-report measures of motor and vocabulary development. Between these ages, infants undergo substantial change in both their linguistic and motoric development. At 6-months-old, infants have just begun understanding their first nouns (Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 1999, 2012) and, from this point, steadily acquire new words each week (Carey, 1978) until experiencing a sudden increase in vocabulary around 18- to 24-months-old (the vocabulary spurt; Goldfield & Reznick, 1990). Analogously, in the motor domain, many 6-month-olds infants have just learnt to sit without support and over time learn to carefully co-ordinate their hand movements, crawl, stand, and walk around without assistance (Adolph & Robinson, 2015). Exploring these associations across this age range provides an opportunity to explore how links between these domains may unfold over time, above and beyond the influence of age. Please note, the present Chapter utilises several different measures than those reported in Chapter 2 and 3. Specifically, the Oxford CDI, rather than UK-CDI, is used as a measure vocabulary size and differing measures of demographics are applied also. This is primarily due to the data reported here being collected first. At the time of data collection, the UK-CDI was not yet available for researchers to use (i.e., it was embargoed while in press) and more objective measures of SES were applied elsewhere in this thesis with the aim to better capture SES. Due to experimenter oversight, ethnicity was not measured in the present study. This was addressed in all future data collection.

4.3. Method

4.3.1. Ethical Approval

This study is associated with ethics application number EC.19.03.12.5616A and was approved by the Cardiff University School of Psychology Ethics Committee.

4.3.2. Participants

Eighty-three caregivers anonymously completed an online survey regarding their infant aged between 6- and 24-months-old (52 female, M = 16 months, SD = 4.97 months, *range* = 6.66-23.80 months). Families were recruited via social media posts and adverts, email invites via the Tiny to Tots Research Panel (a database of families based in Cardiff and South Wales interested in developmental research), and email invites via Healthwise Wales. Healthwise Wales is a Health and Care Research Wales initiative, which is led by Cardiff University in collaboration with SAIL, Swansea University (Hurt et al., 2019; Jones et al., 2014; Townson et al., 2020). All infants were monolingual, English-hearing infants. Infants were classified as monolingual if they were exposed to 75% or more English at home and/or in care settings (e.g., nursery), a common threshold for establishing monolingualism in studies exploring infant language development (Bergelson & Swingley, 2012, 2013, 2015). All infants were born full term (i.e., 37 weeks or later) and were reported as typically developing with no known developmental delays. Seventy-six families were based in Wales and seven were based in England. Details about infant and caregiver ethnicity were not collected. An additional 58 parents responded to the online survey but were excluded due to their infant hearing less than 75% English at home (n = 19), having a history of developmental delays or difficulties (n = 7), premature birth (n = 5), experiencing hearing difficulties (n = 4), or due to contributing high levels of missing data (n = 23). Exclusion details due to missing data are described in more detail in the **Data Preparation** section.

The average age of the responding caregiver was 32 years (SD = 4.84 years, *range* = 22-44 years). Five parents (6%) were educated up to GCSE (i.e., high school) level, 7 had an vocational qualification or equivalent diploma (8.4%%), 8 completed A-Levels (9.6%), 41 (49.4%) had Bachelor's degrees, 14 (16.9%) had Master's degrees, 6 (7.2%) had an M.D., P.h.D., or equivalent, and 2 parents (2.4%) reported having a different (i.e., unlisted) education type. Respondents also completed an item measuring subjective, self-report of socioeconomic status using an adaptation of the MacArthur Scale of Subjective Social Status (Adler et al., 2000). This measure has been found to correlate highly with objective measures of socioeconomic status (e.g., education, income) without asking participants to reveal personal details about their income or employment (Ostrove et al., 2000). Participants used a vertical slider with "bottom" and "top" labels with scores ranging from 0 to 100. The item aims to briefly gauge where an individual sees themselves relative to others in society in terms of income, education, and employment. Specifically, caregivers were asked to place themselves on the slider in relation to the following statement: "At the top are the people who are the best off, those who have the most money, the most education, and the most respected jobs. At the bottom are the people who are the worst off, who have the least money, the least education, and the least respected jobs or no job. Where would you place yourself on the slider? Please indicate on the slider where you think you stand at this time in your life, relative to others in the United Kingdom." Caregivers used the full scale but gave an average ranking of 53.8 (*SD* = 19.4, *range* = 0-99).

4.3.3. Parent-Report Measures

Caregivers completed all measures through an anonymous online survey hosted by REDCap (Research Electronic Data Capture; Harris et al., 2009, 2019).

4.3.3.1 Oxford-Communicative Development Inventory

The Oxford-CDI (Hamilton et al., 2000) is a parent report measure of vocabulary size used across the first two years of life. For this study, the extended version was applied which includes a total of 552 items compared to the standard 416 items. Caregivers indicate on a checklist whether their infant understands or produces each word, yielding scores for both production (number of words reported to be said) and comprehension (number of words reported to be understood, including words reported to be said). Many of the caregivers recruited were completing the questionnaire regarding younger infants who do not yet say any or many words (i.e., younger than 12-months-old). For this reason, caregivers were reminded that the measure is appropriate for a broad age range of children and that there may be words that their baby does not yet understand or say.

To explore links with verb and noun comprehension, all verb and noun items were extracted from the CDI. As described in Chapter 1 (see **2.4.3.1**), CDIs often do not include several verbs that represent some of the earliest actions and motoric skills infants learn to do (e.g., clap, crawl, wave). For this reason, additional verbs were added that describe some of the earliest actions and gestures that children learn to perform. Here, including verbs that describe children's early actions was particularly important when trying to accurately capture infants' knowledge of verbs, as studies show that infants' own actions shape their word learning (Schroer & Yu, 2022; L. B. Smith & Yu, 2008) and this study aimed to explore links between infants' actions and motor skills. That is, children may first learn the names for actions they can already do. Therefore, to best capture infants' verb knowledge, 17 additional verb items were included alongside the existing 69 verb items present in the Oxford-CDI, resulting in a total of 86 verbs[19]. These verbs were derived from actions described in the Early Motor Questionnaire (Libertus & Landa, 2013) and MacArthur-Bates: Actions and Gestures (Fenson et al., 1994) which measure actions and motor skills children typically use in the first years of life. Items that described gestures or actions that children typically learn to use during early development and did not already feature in the Oxford-CDI, were included. The additional items were *brush, build, clap, crawl, dig, fly, lick, nod, pat, point, pour, shake, sit, sniff, spit, talk,* and *wave*. A list of the additional verb items and where in the EMQ and M-CDI: A&G they were selected from can be found in **Appendix A**. For nouns, 359 nouns were counted in the CDI[20].

Word comprehension scores are computed by summing the total number of words understood and the total number of words said. Production scores equal the total number of words said. For verbs, there was a total possible score of 86 verbs. For nouns, there was a total possible score of 359 nouns. For all items in the CDI including verbs and nouns as well as animal sounds, adjectives, prepositions, question words, pronouns, and quantifiers, there was a total possible score of 568 for both comprehension and production. Typically, in the extended Oxford-CDI, scores are out of 569. However, responses for one item were not collected (see **Footnote 2**) and, thus, scores were out of a total 568.

4.3.3.2 Early Motor Questionnaire

Infants' motor development was assessed using the Early Motor Questionnaire (EMQ; Libertus & Landa, 2013). Across 128 items, the EMQ uses parent report to assess the presence of motor skills and behaviours. The EMQ is divided into three sections that organise items by motor skill types: gross motor skills (i.e., whole body skills; 49 items), fine motor (i.e., manual skills; 48 items), and perception action abilities (i.e., sensory skills; 31 items).

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[19] The original extended Oxford-CDI contained 70 verb items. Due to experimenter error, responses for the item *write* were not collected. Therefore, results in the described data included 69 of the original verb items, 17 added verbs and, thus, a total of 568 words in the checklist.

[20] Several nouns describing internet phenomena (e.g., Facebook, Skype) were deemed as too abstract for the current sample and, thus, were not included in noun comprehension scores. This excluded seven items from noun comprehension scores.

Parents respond using a 5-point scale that ranges from -2 to +2 which relates to how certain the parent is that they have witnessed their child producing a motor skill. A rating of -2 is given if a parent is certain that their child has not or cannot complete a motor skill. In contrast, +2 is used when a parent can remember a specific instance when they witnessed their child using a motor skill. Parents are encouraged to use ratings of zero sparingly, which is used to indicate uncertainty as to whether their child can do a particular action. The EMQ has high convergent and concurrent validity, with EMQ scores correlating highly with standardised, examiner-administered assessments of early motor development (e.g., Mullen Scales of Early Learning, Peabody Developmental Motor Scales; Libertus & Landa, 2013). The present analyses are focused on infants' total scores but analogous analyses with fine and gross motor skills can be found in **Appendix G**. Scores are calculated by summing together responses for each given section. Total motor scores are summed across all questions with scores ranging from -256 to 256. Gross motor scores ranged from -98 to 98, and fine motor scores ranged from -96 to 96.

4.4. Results

The results are organised into three sections. First, preliminary analyses explored associations between infants' age and motor skills as well as between infants' age and vocabulary size (for verbs, nouns, and all words in the CDI). I explored these relations as age is typically associated with both motor and language development. Second, relations between infants' motor skills and word comprehension for verbs and nouns were examined separately. Associations between motor skills and total vocabulary size were also explored, based on existing findings in the literature. Finally, to explore whether motor development has a stronger association with verb than noun comprehension, the associations between infants' motor skills and word comprehension for these word types were compared. Word comprehension scores, rather than production scores, were used across all analyses as most infants were reported to say few or no verbs in the sample (see **4.4.2. Descriptives**). Across analyses, infants' total EMQ scores were used as a measure of motor capacities. Additional analyses with infants' fine and gross motor skills are described in **Appendix H**.

The data and analysis script are available at https://osf.io/mbn94/?view_only=8f9e3fd67e3d4fc5a7eb562626229b12

4.4.1. Data Preparation

Prior to scoring, participants with large amounts of missing data were identified and removed from analyses. Several participants had large amounts of missing data. This was due to participants being able to skip any questions they did not wish to answer, in line with ethical principles provided by Cardiff University School of Psychology Ethics Committee. Based on frequencies of missing data, per measure, I identified a threshold for exclusion. Specifically, I noted that most participants had no more than four missing responses, per measure. In contrast, participants with large amounts of missing data had on average had 272 missing items (*SD* = 212) for the Oxford-CDI and had 56 missing items (*SD* = 59.5) for the EMQ. Twenty-three participants were identified to have disproportionate missing data, due to not completing the measures and were excluded from analyses. These participants either did not complete any items or failed to complete most items for either the Oxford-CDI or the EMQ or both.

The final sample included in analyses had data missing for no more than four items on either the Oxford-CDI or EMQ. On average, the final sample had missing data for 0.82 items on the Oxford-CDI (*SD* = 1.11) and 0.43 items on the EMQ (SD = 0.83). Any individual missing data points in the final sample were replaced with zero. For CDI items, a score of zero indicates not understanding or saying an item, whereas, for the EMQ, this indicates that parents do not know whether their child can perform a given action.

4.4.2. Descriptives

Table 4.1
Descriptive statistics for motor skill and vocabulary scores

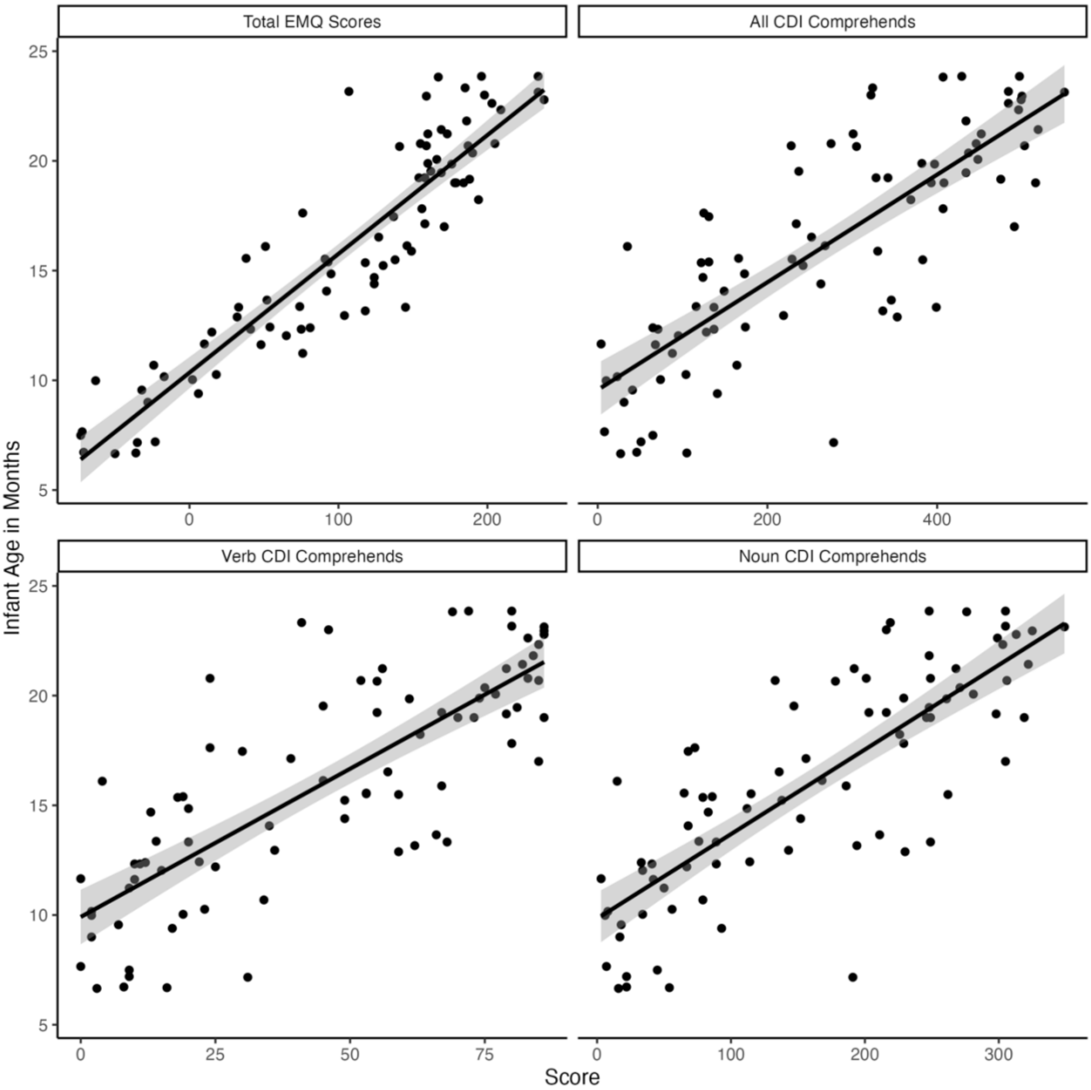
		Mean Score	SD	Range
CDI	All Words Comprehends	262.41	163.62	4-550
	All Words Says	80.66	115.68	0-466
	Verbs Comprehends	45.06	29.07	0-86
	Verbs Says	8.51	18.15	0-83
	Nouns Comprehends	159.98	103.76	3-349
	Nouns Says	53.35	76.50	0-295
EMQ	Total Score	104.36	83.96	-73-238
	Fine Motor Score	25.13	26.53	-27-87
	Gross Motor Score	46.47	40.31	-44-98

Note: CDI: Oxford Communicative Development Inventory. CDI scores refer to the number of words reported to be understood and said. Comprehension and production scores are reported for all items in the measure, verb items, and noun items. EMQ: Early Motor Questionnaire. Total scores and subscale scores for fine and gross motor skills are reported.

4.4.3. Preliminary Analyses

Associations between infants' age (in months) and total EMQ score, and CDI comprehension scores were explored. Visual inspections of the distributions revealed that age, EMQ scores, and vocabulary scores deviated from normality, supported by Shapiro-Wilk tests ($p >. 001$). Therefore, non-parametric Spearman's correlations were applied. All tests were one-tailed. Statistical significance was assessed at an α of .05 and Bonferroni corrections were applied to p-values to correct for multiple comparisons. Please note, from this point onwards, Bonferroni corrections describe in an adjusted p-value in text, rather than the use of an adjusted α level. A strong positive correlation emerged between age and EMQ scores (see **Figure 4.1**; $r_s = .90$, $p < .001$). Age was also positively associated with infants' total, verb, and noun comprehension scores, (see **Figure 4.1**; $r_s = .80$, $p < .001$, $r_s = .79$, $p < .001$, $r_s = .80$, $p < .001$), respectively. These associations show that, as would be expected, motor development and vocabulary development are strongly related to infants' age. As such, age will be controlled for in all subsequent analyses. Controlling for age ensures the unique relation between motor and language development can be explored.

Figure 4.1
Associations between age, motor skills, and vocabulary scores



Note: Ribbons represent standard error. X-axis scale varies as a function of the measure: total EMQ scores, total CDI score, verb CDI score, or noun CDI score. Y-axis shows infant age in months.

4.4.4. Associations Between Motor Skills and Vocabulary Size

To test associations between infants' motor skills and their verb and noun vocabulary, correlations were performed. An additional correlation was performed to examine the relation between motor skills and infants' total CDI comprehension scores to replicate findings from previous literature. Subsequent partial correlations were conducted to control for age. As described above, both EMQ and CDI scores deviated from normality and, thus, Spearman's non-parametric tests were used throughout. All tests were one-tailed. Statistical significance was assessed at an α of .05 and Bonferroni corrections were applied to *p*-values to correct for multiple comparisons.

Correlations revealed strong positive associations between motor skills and verb comprehension scores ($r_s = .82$, $p < .001$), noun comprehension scores ($r_s = .83$, $p < .001$), and total comprehension scores ($r_s = .83$, $p < .001$). These associations remained significant after controlling for age. Partial correlations revealed significant positive associations between motor skills and verb comprehension scores ($r_s = .39$, $p < .001$), noun comprehension scores ($r_s = .40$, $p < .001$), and total comprehension scores ($r_s = .40$, $p < .001$).

4.4.5. Are Motor Skills Associated More Strongly with Verb Than with Noun Comprehension?

To assess whether the association between motor skills and word comprehension is stronger for verbs over nouns, I fit a binomial generalized linear mixed-effect model (GLMM) with a logit link function (i.e., a logistic mixed effect model) from the *lme4* package (Bates et al., 2015). Logistic mixed effect models are advantageous for analysing categorical language outcomes (e.g., CDI item responses) and extend traditional General Linear Models (GLMs) by accounting for random participant and item effects (Jaeger, 2008). Such models enable the exploration of relations and interactions between fixed effects and outcome variables and can also include control variables by entering them as fixed effects.

The current analysis focused on verb and noun comprehension and, thus, only included these items in the model. The current model included word comprehension as a binary dependent variable (0: Does Not Understand, 1: Understands). Items reported to be "said" were included as understood items. Motor skills (total EMQ scores), word type (verb | noun), infants' age (in months), and the interaction between motor skills and word type were included as fixed effects. In addition, a maximal random effects structure was fit (Barr et al., 2013) with infants as random intercepts with by-participant random slopes for word type and word items as random intercepts with by-word random slopes for motor skills and age. A random intercept only model (infants and word items) and a simple random effects structure model (infants and word items as random intercepts with by participant random slopes for word type) were also fit. Model comparisons revealed that the maximal random effects structure significantly improved the model fit (see **Appendix G**). All continuous fixed effects were centered using the *scale*() function to address collinearity between EMQ scores and infants' age. Word type was sum contrast coded (-.5: verb, .5: noun)[21]. Confidence intervals were computed with the *confint*() function. The model that was estimated used the following *lme4* structure:

Word Comprehension ~ EMQ Score* Word Type + Infant Age + (1 + Word Type | Infants) + (1 + EMQ Score + Infant Age | Word Items)

Table 4.2
GLMM model results: Fixed effects

	Model Summary			
	β	*SE*	*z*	*p*
Intercept	-0.2046	0.2216	-0.923	.356
Total EMQ Scores	1.7404	0.4133	4.211	<.001 ***
Word Type	-0.9154	0.2850	-3.212	.001 **
Infant Age	0.7197	0.4046	1.779	.075
Total EMQ Scores:Word Type	-0.3712	0.1416	-2.622	.009 **

Note: * $p < .05$; ** $p < .01$; *** $p < .001$

Table 4.3
GLMM model results: Random effects

		Variance	Standard Deviation
Word Items	Intercept	4.672	2.162
	Total EMQ Scores	0.076	0.276
	Infant Age	0.112	0.335
Infants	Intercept	2.595	1.611
	Word Type	0.920	0.959

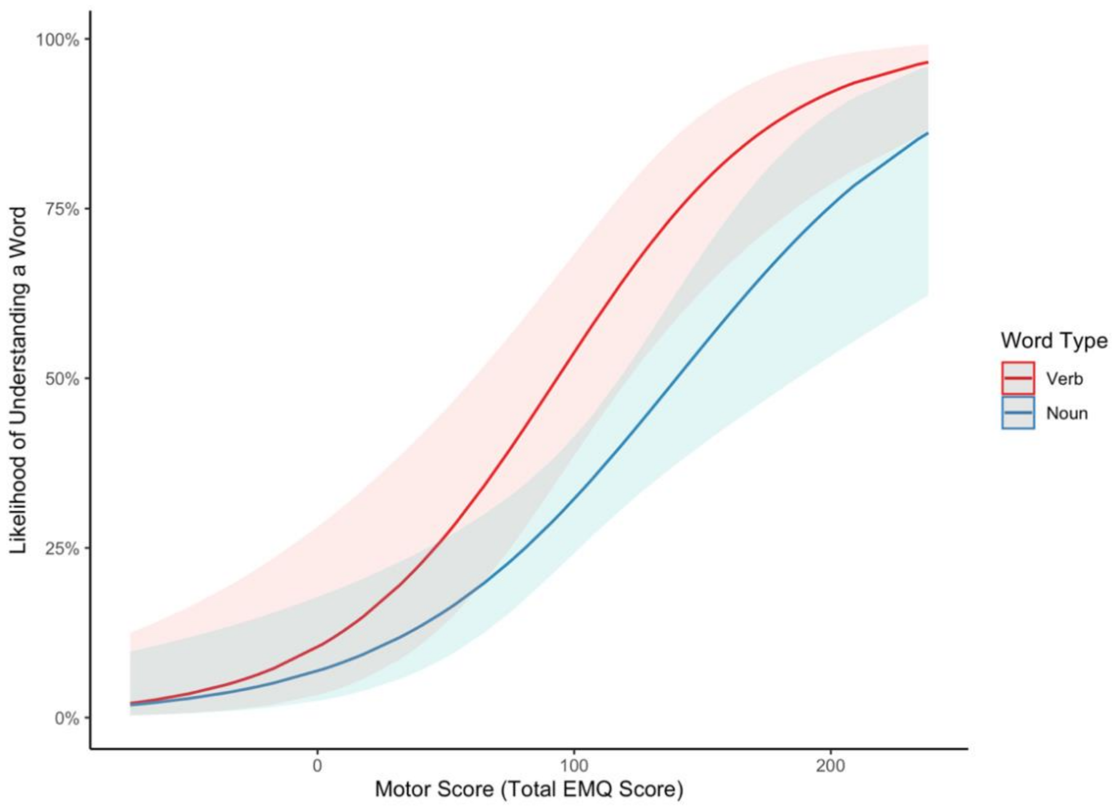
The fixed effects from the model results are described in **Table 4.2** and the random effects are described in **Table 4.3**. The model revealed a significant interaction between motor skills and word type (B = -0.37, CI 95% [-0.65,-0.09], SE = 0.14, z = -2.62, p =. 009). This interaction was followed up using the *emtrends*() function from the *emmeans* package (Lenth, 2021) which compares whether slopes, for each level of a categorical predictor, are

[21] Sum contrast coding of categorical fixed effect interactions essentially "centers" the effect at the grand mean between the two groups and are easier to interpret than treatment coding (i.e., 0 | 1).

statistically different from each other in models with significant interactions between a categorical and continuous predictor. Results showed that the association between word comprehension and motor skills was significantly greater for verbs than for nouns (*estimate* = 0.465, CI 95% [0.117,0.812], *SE* = 0.177, z = 2.62, p = .009, see **Figure 4.2**). That is, for an infant of average age in our sample, motor skills were more strongly linked to the number of verbs comprehended than to nouns comprehended. There was also a significant main effect of motor skills on word comprehension, with the likelihood of understanding a word increasing with greater motor skills (B = 1.74, CI 95% [0.93,2.55], *SE* = 0.41, z = 4.21, p <. 001). A significant main effect of word type also emerged (B = -0.92, CI 95% [-1.47,-0.36], *SE* = 0.29, z = -3.21, p = .001). Thus, the infant of average age in the sample understood a greater proportion of the verbs than they did nouns. The main effect of age was marginal (B = 0.72, CI 95% [-0.07,1.51], *SE* = 0.40, z = 1.78, p = .075).

Figure 4.2

Results from logit mixed effects model showing an interaction between word comprehension, motor skills and word type



Note: The y-axis indicates the likelihood of a word being understood. The x-axis represents total EMQ scores. Estimates for verb items are represented by the red line. Estimates for noun items are represented by the blue line. Ribbons represent 95% confidence intervals.

4.5. Discussion

In this study, I investigated concurrent associations between motor skills and vocabulary development in a sample of infants aged 6- to 24-month-olds, an age range where variability and significant change in language and motor development occurs. Previous literature reports associations between these domains during early development, with increases in motoric abilities being associated with increased linguistic input from caregivers and overall larger vocabularies (e.g., Alcock & Krawczyk, 2010; Choi et al., 2018; Clearfield, 2011; Gonzalez et al., 2019; He et al., 2015; Houwen et al., 2016; Karasik et al., 2014; Oudgenoeg-Paz et al., 2012; Pereira et al., 2014; Schneider & Iverson, 2022; Schroer & Yu, 2022; Suarez-Rivera et al., 2022; Valla et al., 2020; Walle & Campos, 2014; West & Iverson, 2021; Yu & Smith, 2012). In contrast, I examined whether advances in motor skills are associated specifically with verb and noun comprehension. In follow up analyses, I then further investigated whether this relation was stronger for verb, over noun, comprehension.

Correlational analyses revealed strong associations between both verb and noun comprehension (as well as overall vocabulary size) and infants' motor skills, even when controlling for age. That is, the number of verbs and nouns infants were reported to understand increased as motor skills developed, above and beyond the effect of age. Follow up analyses were conducted with statistical models controlling for age, accounting for variability introduced by infants and word items, and exploring potential interactions between word type (i.e., verbs and nouns) and motor skills. This analysis revealed several findings.

First, echoing correlational analyses, increases in infants' motor skills were associated with increased probability of word items, specifically verbs and nouns, being understood. Second, infants in the sample understood, on average, a larger proportion of verbs than nouns. This finding is potentially explained by differences in the amount and diversity of verb and noun items included in the extended Oxford-CDI. Specifically, CDI measures tend to include a small number of verb items (here, 86 including additional items) that represent the proportion of verbs present in children's early productive vocabularies. These items tend to describe simple, "concrete" actions. In contrast, noun items often dominate CDI measures (here, 359) and describe a rich variety of referents, from concrete food items (e.g., apple, banana) to abstract categories (e.g., medicine, ghost). It is possible that the average infant in the sample understood a greater proportion of verbs as many nouns in the measure were still too challenging to comprehend. Importantly, these main effects were qualified by an interaction between motor development and word comprehension, revealing that motor skills were more strongly linked with verb comprehension compared to noun comprehension. No significant effect of age was found in this model, likely due to motor skills being included in the model and controlling for this effect. In the following section, I begin by discussing how associations between infants' motor development and word understanding replicate existing findings in the literature. Then, I describe how results highlighting stronger links between verb comprehension and motor skills enhances our understanding of the cascading influence of motor advances on language development and discuss this as a potential mechanism that infants may exploit to interpret novel verbs.

First, correlational and follow-up analyses confirm previous findings that infants' motor development is associated with their overall vocabulary size. Further, this relation exists not only for general language outcomes but for specific word types, with knowledge of verbs and nouns increasing with motoric gains. For typically developing infants, previous findings already show links between motor skill acquisition and broad language outcomes (Alcock & Krawczyk, 2010; Choi et al., 2018; He et al., 2015; Oudgenoeg-Paz et al., 2012; Ruddy & Bornstein, 1982; Valla et al., 2020; Walle & Campos, 2014; Zuccarini et al., 2018). This study shows that motor developments are also associated with understanding of specific word classes (see also, Oudgenoeg-Paz et al., 2015). Importantly, across all analyses, these relations held when age was controlled for. Indeed, embodied perspectives of word learning have long suggested that the cascading effects of motor development are not simply the result of neurological maturation and general aging alone (Iverson, 2010). Rather, developing motor skills bolsters infants' practice of communicative abilities (e.g., oral motor control, gestures) and re-organises their interactions with the world around them (Campos et al., 2000; Iverson, 2010, 2022). For example, acquisition of motor skills changes the way in which infants see and traverse across physical space, engage with toys and objects, and even the social attention and linguistic input of caregivers (Franchak et al., 2018; Karasik et al., 2014; Kretch et al., 2014; Soska & Adolph, 2014; West et al., 2022; West & Iverson, 2021).

Interestingly, the current data also show that the cascading impact of motor skills on word learning is not uniform across different aspects of language development. Here, I show that verbs hold an especially strong concurrent association with acquired motor skills when contrasted against the relation with nouns. This is not to say gains in motor skills are not important for noun comprehension; certainly, the current analyses show that noun understanding is also related to motor acquisition. Yet, these findings suggest that the acquisition of motor skills may play an especially important role in verb learning. As outlined in Chapter 1, early vocabulary is typically noun dominated and does not reflect the varied linguistic input that children receive, a finding established cross-linguistically (Gentner, 1978). Indeed, several studies of children's vocabulary and word learning in the lab show that children struggle to learn verbs (e.g., Childers & Tomasello, 2002; Gentner, 1978; Gentner & Boroditsky, 2001; Imai et al., 2005, 2008; Kersten & Smith, 2002). Theoretical approaches to word learning suggest that this disparity is not the consequence of intrinsic differences between word classes *per se*, but rather because verbs describe abstract, relational concepts that have highly variable meanings across languages (Gentner, 1978, 2006; Gentner & Boroditsky, 2001). Given these challenges, it is likely that children exploit several word learning mechanisms and environmental cues to ascertain the meaning of a given verb (Gillette et al., 1999; Gleitman, 1990; Naigles, 1990; Samuelson & Smith, 1998; Tomasello, 1992b, 1995).

Feasibly, advancing motor skills may serve as one mechanism through which infants identify and learn the meaning of novel verbs. Support for this view come from recent insights by West et al. (2022) demonstrating that caregivers frequently respond to infants' actions with congruent verbs, resulting in common "action-naming" moments where infants' actions align with the verbs they hear. Interestingly, the authors reported that caregivers of older infants, with larger motor skill and linguistic repertoires, respond to their infants' actions far more frequently and with a greater diversity of verbs. These findings suggest that infants' own actions may bolster their verb learning by shaping the frequency and variability of verbs they hear from caregivers. Conceivably, experience performing such actions may also help organise infants' action concepts across verb naming exposures. For example, active experience with actions helps infants to recognise actions as intentional and goal directed (Gerson & Woodward, 2014a, 2014b) which, in turn, may support infants' understanding of which components of a given action are conveyed in a verb (Sootsman Buresh et al., 2006). Thus, infants' acquisition of motor skills may, in part, support their verb learning.

In contrast, though we know infants' actions can also support their noun learning, it is plausible that motor skills play a smaller role during noun acquisition. For example, research shows infants' object holding and head positioning does support their novel noun learning when it co-occurs with parental labelling (Pereira et al., 2014; Schroer & Yu, 2022; Yu & Smith, 2012). Infants' actions in these moments are thought to reduce referential uncertainty by providing infants with less cluttered visual scenes which helps them to focus on the correct referent. Yet, nouns often describe concrete referents that infants find easy to individuate in the real word and can readily map a novel noun onto a recently familiarised object category from visual experience alone (Pomiechowska & Gliga, 2019). The same cannot be said for verbs, with failure to map a novel verb onto a recently seen action often reported in children younger than 5-years-old (e.g., Imai et al., 2005, 2006, 2008). For this reason, infants may be less dependent on their own actions to infer the meaning of novel nouns but may rely more heavily on them to grasp the meaning of novel verbs. It is also possible that infants' actions may be more beneficial for learning more abstract or relational nouns. Future research could focus a similar set of analyses on abstract nouns compared to verbs, which may possibly fail to detect a difference between verbs and abstract nouns given that concreteness and imaginability may be driving the differences found in the current analyses (Ma et al., 2009; McDonough et al., 2011).

4.5.1. Limitations

The current findings suggest that cascading influences of motor gains may support different aspects of infants' word learning in different ways. However, the current design cannot test or speak to direct or causal consequences of motor development on infants' language skills. Further, motor and vocabulary development were assessed using parent-report measures. Such measures boast clear benefits, namely being validated, widely used and well-studied, cost-effective, and efficient techniques for gaining insight into areas of development that can be challenging and time-consuming to capture in laboratory settings. Studies show that EMQ scores are tightly correlated with examiner-administered motor assessments (Libertus & Landa, 2013) and that caregiver responses on the Oxford-CDI often align with infants' word comprehension measured in looking time studies (Styles & Plunkett, 2009). Yet, parent-report measures can be prone to over or under-estimations of children's current capabilities (Houston-Price et al., 2007; Tomasello & Mervis, 1994). Thus, though such measures likely provide reasonable estimations of infants' current motor and vocabulary development, future research should seek to corroborate these relations under carefully controlled conditions.

4.5.2. Future Directions

Additional experimental research is needed to explore whether motor skills indeed support infants' verb learning to better understand the potential mechanisms at play. As such, future work should aim to directly test whether verb input from caregivers during infants' actions are associated with subsequent verb learning. For example, in the context of noun learning, several studies have shown that infants' object manipulation, paired with parental linguistic input, supports novel noun acquisition (Pereira et al., 2014; Schroer & Yu, 2022; Suarez-Rivera et al., 2022; Yu & Smith, 2012). Rigorous lab-based studies should also aim to explore whether motoric training with novel actions paired with novel verbs, contrasted with passive observation (e.g., Gerson et al., 2015; Gerson & Woodward, 2014b), better supports infants' verb learning.

4.6. Conclusion

This study broadens understanding about the cascading impacts of motor skill acquisition on different aspects of children's word learning. Here, I show that verb comprehension, in particular, is tightly linked with motor development across the first two years of life. Nonetheless, motor skills were also strongly correlated with the size of children's receptive noun vocabulary, suggesting that motor skills broadly support early language development. Verb referents are abstract and typically challenging to identify in the world. As such, it is possible that infants' own actions may foster early verb learning by creating opportunities for children to learn about actions and receive increased verb labelling from caregivers.

Chapter 5. General Discussion

5.1. Introduction

Though children struggle to learn verbs compared to nouns (Gentner, 1978, 1982, 2006; Gentner & Boroditsky, 2001), verbs are often found in children's early productive vocabulary (Fenson et al., 1994; Maguire et al., 2006). Much research and many theoretical perspectives have focused on exploring *how* children identify verb referents and integrate verbs into their lexicons (e.g., Gleitman, 1990; Golinkoff et al., 1995; Naigles, 1990; Smith, 2000; Smith et al., 1996; Tomasello, 1992, 1995). Far less research has explored by what age the capacity to understand verbs emerges, despite several recent studies providing insight into when infants first learn nouns (e.g., Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 1999, 2012). The overarching aim of this thesis was to establish if infants comprehend the meaning of several early verbs by the age of 10-months-old, explored across Chapters 2 and 3. Recent work has also reported links between infants' word comprehension, their action experiences, and motor development (Alcock & Krawczyk, 2010; Clearfield, 2011; Gonzalez et al., 2019; He et al., 2015; Karasik et al., 2011, 2014; Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012, 2015, 2016; Oudgenoeg-Paz & Rivière, 2014; Schneider & Iverson, 2021; Suarez-Rivera et al., 2022; Tamis-Lemonda et al., 2013; Tamis-LeMonda et al., 2019; West et al., 2019, 2022; West & Iverson, 2017, 2021). The secondary aim of this thesis was to explore if infants' verb comprehension is associated with their motor development. This aim was the focus of Chapter 4. In this final chapter, I will summarise the key empirical findings of this thesis before discussing implications of the findings, limitations of the research conducted, and suggest some potential avenues for future research.

5.2. Summary of Findings

5.2.1. Measuring Verb Comprehension: Looking While Listening Paradigms

In Chapter 1, I outlined three fundamental skills that theorists of word learning suggest children require to learn a verb (Gentner, 1982; Golinkoff et al., 2002). Children must be able to (1) identify a verb within continuous speech, (2) attend to actions and form action categories, and (3) map a verb onto an action concept. Within Chapter 1, I described evidence from studies of social and cognitive development that suggest many of these capabilities emerge within the first year of life. Specifically, by approximately 10-months-old, infants can conceptualise actions and events (Baldwin et al., 2001; Pruden et al., 2012, 2013; Pulverman et al., 2008, 2013; Sharon & Wynn, 1998; Woodward, 1998; Woodward et al., 2009; Wynn, 1996), segment some words from speech (e.g., Jusczyk, Hohne, et al., 1999; Jusczyk, Houston, et al., 1999; Jusczyk & Aslin, 1995; Saffran et al., 1996; Werker & Hensch, 2015), and have begun mapping words onto referents (Bergelson & Swingley, 2012, 2013, 2015; Nomikou et al., 2019; Tincoff & Jusczyk, 1999, 2012). Several studies also show that around 14-months-old, infants have developed more sophisticated skills in event processing (Pruden et al., 2012), verb segmentation (Nazzi et al., 2005), and word learning more broadly (Bergelson, 2020; Bergelson & Swingley, 2012, 2013, 2015, 2018). Therefore, in Chapter 2, I chose to focus my exploration of verb comprehension during infancy in children aged 10 and 14 months.

Like several previous studies (Bergelson & Aslin, 2017; Bergelson & Swingley, 2012, 2013), I assessed infants' word comprehension via a technique known as the looking while listening paradigm (Fernald et al., 2008; Swingley, 2011), both online and in the lab. Infants were presented with pairs of videos depicting actions, while the target action was labelled with a verb. I discovered that, as expected, 14-month-olds looked longer at the target verb after hearing it labelled. Although this effect was not detected when examining looking behaviour by items (possibly due to reduced power to detect effects when looking behaviour was not aggregated across trials), a link was also found between 14-month-olds' looking behaviour and their communicative action and gesture capabilities: Increased target looking was associated with a greater number of action/gesture skills. A marginal positive association was also found between 14-month-olds' looking behaviour and the number of actions infants could perform that are associated with the verbs in the task (e.g., being able to drink from a cup, walk). In contrast, and contrary to my hypothesis, 10-month-olds did not look longer at the target across items, though they comprehended a small number of verbs when looking behaviour was examined by item pair, adding to previous work reporting that infants already understand some abstract words at this age (Bergelson & Swingley, 2013; Nomikou et al., 2019). During Chapter 2, I discussed some potential reasons why infants may have failed to show comprehension of the verbs in the task, including attentional load, visual preference, or needing additional supportive cues (e.g., familiar speaker, verb framing). Ten-month-olds' looking behaviour was not associated with action performance skills or motor development. For both ages, no correlations were found between infants' looking behaviour and their parent-reported vocabulary. Finally, I found no significant differences in 10-month-olds' looking performance between the online and eye-tracking study, with visual plots showing a similar pattern of looking behaviour in both tasks. As such, these findings provided an important within-study comparison of online and eyetracking looking while listening tasks, aligning with recent research demonstrating that results from similar online paradigms largely align with lab-based results (Lapidow et al., 2021; Nelson & Oakes, 2021; Smith-Flores et al., 2022).

5.2.2. Measuring Verb Comprehension: Event-Related Potentials

As described in Chapter 2, I found that 10-month-olds did not reliably look longer at target actions after hearing a verb in two looking while listening tasks. One interpretation of these findings is that, at this early stage of language development, 10-month-olds are not yet able to understand verbs. However, a lack of target looking in such paradigms can be challenging to interpret. Whilst it is possible infants failed to discriminate between the actions or did not associate verbs with the exemplars, infants' looking performance could also be driven by other factors such as visual preference (Aslin, 2007). That is, infants may have a visual preference for one of the videos or find them both equally attention grabbing, overriding the tendency to look at a visual target that matches with the spoken label (Golinkoff et al., 1987). During data processing, I controlled for visual preference by using a bias-correcting computation that has been used in several word comprehension studies (e.g., Bergelson & Swingley, 2013, 2013, 2015). Such computations aim to reduce the likelihood that target looks are driven by visual preference (i.e., aiming to reduce the likelihood of false-positives) but can also contribute to noise in the data which may wash out any otherwise observable effect (Swingley, 2011).

In Chapter 3, to provide insight into these findings, I investigated verb comprehension in 10-month-olds by examining the N400 ERP response. In this task, infants were presented with a video of an action and then heard a verb that either matched or mismatched the action. As such, these tasks are less impacted by visual preference, are less cognitively demanding (e.g., only one visual and one audio stimulus to attend to and process) and may be a more sensitive measure of word comprehension. Infants were tested on the same verb items as in Chapter 2 and the vast majority of infants came from the same sample as infants took part in both of these tasks during data collection. Here, I found that 10-month-old infants understood the verbs in the task, evidenced by a greater N400 response (in frontal regions) to action-verb mismatches when compared against action-verb matches. This effect was detected as a result of exploring a borderline significant interaction between condition and brain region, as I aimed to explore any potential interactions with condition. As such, this effect should be interpreted carefully given that the interaction was not significant. Whilst taking this consideration into account, the current work largely corroborates for previous work revealing that 10-month-olds can understand some abstract words (Bergelson & Swingley, 2013; Nomikou et al., 2019). Specifically, this study demonstrates that by at least 10-month-old, infants likely understand some verbs as evidenced by an N400 response. These findings also suggest that the paradigms used in Chapter 2 may not have been sensitive enough to detect 10-month-olds verb knowledge. Though the N400 response is typically also found in central and/or parietal regions, previous studies using scenes, actions, or gestures as stimuli typically report more frontal distributions in infants (Helo et al., 2017; Sheehan et al., 2007) and adults (Kutas & Federmeier, 2011), possibly due to simultaneous motor region recruitment (Amoruso et al., 2013). I also investigated whether the magnitude of infants' N400 responses was associated with their vocabulary development. A marginal positive association was found between the magnitude of the N400 effect and the number of words infants were reported to say. This finding broadly aligns with previous literature that reports associations between infants' productive vocabulary and the N400 effect (Borgström et al., 2015a, 2015b; Friedrich & Friederici, 2010; Helo et al., 2017; Rämä et al., 2013; Torkildsen et al., 2008, 2009). No other associations were found.

5.2.3. Associations Between Word Comprehension and Motor Development

In Chapter 1 and Chapter 4, I described how several studies have reported links between infants' motor development and their vocabulary acquisition. Broadly, this literature reports earlier onset of motor skills and larger motor repertoires being associated with larger vocabularies, both concurrently and longitudinally. Motor gains are thought to provide infants with new opportunities for exploration (of both objects and harder to reach environments), different visual perspectives, and opportunities for novel social interactions with caregivers. So far, many of these studies focused on general measures of language development, namely, vocabulary size.

However, some recent research has considered whether motor development may be particularly important for aspects of language that convey sensorimotor information (e.g., Oudgenoeg-Paz et al., 2015; West et al., 2022). Specifically, children's own actions afforded to them by motor gains may create unique opportunities for children to learn about verbs. In Chapter 4, I extended this body of work by asking whether the association between motor development and language acquisition is especially important for verbs (relational terms conveying sensorimotor information) compared to nouns (stable, concrete entities) in a sample of 6- to 24-month-olds. Whilst both verb and noun comprehension were related to infants' motor development, with increases in motor abilities linked with larger vocabulary, I found that this association was significantly stronger for verbs than for nouns. These findings provide correlational evidence that language learning may be an embodied process, whereby motor development is tightly linked with children's acquisition of verbs.

5.3. Contribution of the Thesis

When children begin saying words in their early life, verbs feature far less often in their word production compared to nouns, which tend to dominate early language. Despite this delay in saying verbs, the findings from this thesis suggest that infants have begun comprehending verbs many months before verbs reliably appear in their productive vocabulary. Indeed, the capacity to understand verbs seemingly emerges in line with several other cognitive and social abilities necessary to conceptualise actions, extract words from speech, link words and referents together, and understand the intentions of others. These findings extend previous work to show that infants' understanding of verbs is broader and more extensive than previously reported, with ERPs showing that 10-month-old infants understand some verbs. This thesis also highlighted the potentially important role motor development may play in infants' verb learning experiences, with verb comprehension being more strongly associated with motor development than noun comprehension.

To measure infants' verb comprehension, converging behavioural (looking time measures) and neurophysiological (ERPs) approaches were used. The looking time tasks were conducted both online and in the lab. This investigative approach had several advantages. First, using two looking while listening tasks, with highly similar designs, online and in lab demonstrated that similar patterns of results can be found using both online and in lab techniques to measure early word comprehension. Such a finding is particularly important in light of the recent pandemic, forcing developmental science online and with rising interest in collecting looking data online. Second, using converging behavioural and physiological techniques enabled us to conclude whether 10-month-olds truly did not understand the verbs tested or whether infants' looking behaviour was influenced by the specific demands and characteristics of the looking while listening tasks. That is, in Chapter 2, 10-month-olds generally failed to demonstrate recognition of verbs in the looking while listening tasks. However, using ERPs in Chapter 3, I found greater N400 amplitudes to incorrect pairings of actions and verbs, demonstrating that 10-month-olds did indeed recognise the verbs used across the tasks. In fact, the use of the same stimuli and largely the same sample of infants (the data collected from infants in Chapters 2 and 3 was collected in one session) taking part in both tasks suggests that failure to look at the target items across the looking while listening paradigms was unlikely due to the specific stimuli or sample used. Rather, failure to detect evidence of infants' verb comprehension may have either been a result of the way the stimuli were presented and/or because of noise present in the dependent measure. Collectively, these results also demonstrate that null findings in looking time measures of word comprehension should be interpreted cautiously (as null results should be in general) and are best accompanied by additional physiological measures, where possible (see Aslin, 2007, for a discussion).

Links between infants' verb comprehension and motor development were assessed multiple times across the thesis, with verb comprehension measured using looking times and parent-report. When exploring links between language and motor development, most studies have focused on vocabulary measured by CDIs. As such, one strength of this thesis is the use of several empirical measures of vocabulary providing a more comprehensive examination of word understanding by utilising parent-report as well as behavioural and neural measures. Extending this, Chapter 4 focused on exploring whether the association between verb comprehension and motor development was stronger than that with noun comprehension. Though some studies have begun exploring the links between relational word learning and motor development (e.g., Oudgenoeg-Paz et al., 2015; West et al., 2022), Chapter 4 described a novel investigation as to whether this link may be more beneficial for some aspects of language compared to others (i.e., verbs compared to nouns).

5.4. Implications of Findings

Theorists of word learning suggest that the ability to understand verbs relies on infants having several cognitive capacities available to them. As I outlined in Chapter 1, several studies have reported that infants have begun segmenting words from speech, attending to actions and individuating actions, categorising actions, and have begun mapping some words on referents. Yet whether infants could specifically map verbs onto actions, and thus, have begun understanding their first verbs, was still unclear. The findings from this thesis have provided insight into when infants have acquired the ability to map verbs onto actions by directly testing and showing that infants can associate verbs with action exemplars by at least 10-months-old. Therefore, these findings suggest that, during the first year of life, infants likely have acquired many of the cognitive and conceptual prerequisites argued to be necessary for verb learning to occur (Gentner, 1978, 2006; Gentner & Boroditsky, 2001; Golinkoff et al., 2002).

There are also important implications for theories of word learning that make predictions about how children come to learn verbs. Several theories make predictions about how young children come to learn new words. For example, the social-pragmatic account (Tomasello, 1992a, 1992b, 1995) asserts that children determine verb meanings by inferring a speaker's intent, relying on social cues such as eye gaze, intentional actions, and gestures. In contrast, syntactic bootstrapping (Gleitman, 1990; Naigles, 1990) presumes that children exploit syntactic information within a sentence to infer the meaning of a novel verb. Other theories suggest that children use domain-general associative learning processes or may rely on innate/learned biases that help them to constrain the number of potential word-to-world hypotheses (Golinkoff et al., 1994; Markman, 1990; Nelson, 1988; Samuelson & Smith, 1998; Smith, 2000; Smith et al., 1996). These theories paint a picture of several plausible mechanisms that may support children when they are learning new words. Nonetheless, whilst the findings from Chapter 3 demonstrate that infants understand the meaning of several verbs by 10-months-old, it is currently unclear whether the aforementioned mechanisms would support the learning of verbs. That is, to date, much of the research exploring these mechanisms of word learning have primarily been tested in older infants/toddlers or have yet to be tested with verbs directly. The findings reported in this thesis are unable to attest to the specific mechanisms that infants utilise to grasp the meanings of their first verbs. However, knowing that infants understand verbs as early as 10 months provides an important "jumping-off point" for such mechanisms to be tested. I discuss potential avenues for future research in a later section.

The findings from Chapter 4 revealed that the relation between motor development and vocabulary acquisition during the first two years of life is stronger for verb understanding than it is for noun understanding. These results have interesting implications for theories that envision language as an embodied process, such as the developmental cascades account/dynamic systems theory and theories of embodied/grounded cognition (Iverson, 2010, 2021, 2022; Oakes & Rakison, 2020; Piaget, 1952; Thelen, 2000a, 2000b; Thelen & Smith, 1996). Within these frameworks, studies have begun shedding light on how infants' varying motoric experiences can influence their real-life interactions with objects, environments, and people which, in turn, supports their language learning. Though some studies have found that parents increase their verb production as infants produce more actions and use a wider range of motor skills (West et al., 2022), whether this in fact impacts infants' later verb learning has not been explored. My findings from Chapter 4 (though correlational in nature) suggest that there is a link between infants' actions and their verb comprehension. Given that this relation was stronger than that with noun comprehension, this suggests that children's own action production may relate to how children interpret and process verbs more so than it does with nouns (Smith, 2010). For example, as early nouns typically describe concrete objects (which are visually stable and often easy to individuate and conceptualise) it is possible that there are many opportunities for infants to learn about objects and object names through visual exposure alone (e.g., Pomiechowska & Gliga, 2019). Even though object handling does create opportunities for noun labelling (Yu & Smith, 2012), it is possible that infants' own actions create unique opportunities for them to learn about actions and verbs given that actions are abstract, brief, and challenging to conceptualise. For example, we already know that infants exploit their own actions to better understand actions (e.g., Gerson et al., 2015; Gerson & Woodward, 2012, 2014a, 2014b) and that parents use infants' actions as opportunities to label verbs (West et al., 2022). The findings from Chapter 4 open up exciting new avenues for research to explore the potential close links between children's actions and verb learning.

5.5. Limitations

The studies in this thesis had several limitations. Here, I primarily describe limitations introduced by the (1) the methods used, (2) the samples collected, and (3) the descriptive and cross-sectional nature of the research, discussing how these issues may constrain the conclusions drawn. First, several aspects of children's development were measured using parent-report. For example, across the thesis, children's motor development was measured using the EMQ (Libertus & Landa, 2013), a parent-report measure of motoric development. Similarly, children's broader vocabulary scores were also derived using CDIs (Alcock, Meints, et al., 2020; Hamilton et al., 2000); however, efforts were made across this thesis to measure verb comprehension using a variety of converging empirical approaches. Parent-report measures can be prone to under- or over-estimation of children's abilities (Houston-Price et al., 2007; Tomasello & Mervis, 1994), and thus, may not always accurately capture aspects of children's development. That said, the EMQ was carefully selected as a measure of motor development as scores on this measure have previously been found to correlate highly with those of examiner-based measures of motor development (Libertus & Landa, 2013).

Further, parents are generally reported to accurately estimate their infants' motoric capabilities on parent-report measures of motor development (Goldstein, 1985). I also chose to include CDIs as measures of children's broader vocabulary as other studies have found that scores from CDIs align with empirical measures of word understanding (Styles & Plunkett, 2009). In this thesis, I found mixed evidence that parents' assessments of their children's word comprehension aligned with empirical measures. For example, no associations were found between infants' verb comprehension measured by looking times or ERP amplitudes and verb comprehension reported by parents for the task items. On the other hand, a marginal association was found between the N400 effect and children's overall productive vocabulary, which may suggest that parents, understandably, best estimate word knowledge specifically for the words they hear their children say. As the infants included in our sample were not yet saying any verbs, I was not able to explore whether there were links between infants N400 and the number of verbs they could say. Future research should endeavour to explore this link by collecting data from older infants and toddlers who can say some verbs. In addition, future studies should aim to measure infants' motor development using more ecologically valid assessments as scientists increasingly suggest that the conclusions drawn about motor development, and its links with cognition, can be constrained by the tools used to explore it in developmental psychology (Adolph, 2020b, 2020a). Despite this limitation, the links detected between motor development and word acquisition in Chapter 4 is particularly promising and potentially suggests that even stronger links could be detected if more refined and sensitive measures were used.

It is also important to acknowledge that primarily white infants from families with high socioeconomic statuses took part in the reported experiments, with all participants hearing English as their native language. This is important to consider given the social, cultural, physical, and linguistic environments we develop within can shape our cognition and physical development. With much of developmental research being focused on English-hearing infants from WEIRD (western, educated, industrialised, rich, and democratic) countries, the phenomena we study may not accurately describe the developmental trajectories, cognitive processes, and environmental contexts experienced by many infants (Nielsen et al., 2017; Oakes, 2021). For example, recent recommendations have stressed the importance of investigating languages beyond English, which tend to dominate much of cognitive science (see Blasi et al., 2022, for review and discussion). Reliance on English as a general "model" of language mechanisms and linguistic functioning can skew our understanding of language development due to the distinct linguistic and social features present in English (Blasi et al., 2022). Indeed, researchers have long discussed how verb learning timelines and processes described with English speaking children may not be as applicable for children exposed to other, more “verb-friendly” languages, such as Japanese, Mandarin, and Korean, that place greater focus on verb tokens within sentences (e.g., Chen et al., 2015; Ma et al., 2009; Maguire et al., 2010; Tardif, 1996; Tardif et al., 1999). As such, the conclusions of the current thesis may primarily enlighten our understanding of the onset of verb learning in English hearing (or similar Germanic language hearing) infants.

Additionally, the samples described across all chapters had, on average, high socioeconomic statuses with most parents educated up to at least Bachelor’s degree with household incomes that exceeded the national average within the UK (Office for National Statistics, 2022). Children of high SES households tend to receive increased parental linguistic input and often have larger vocabularies (e.g., Fernald et al., 2013; Hoff, 2003). Though it is an open question, the typical age of acquisition for verb comprehension or early verb diversity may be different for some infants from lower SES families or infants that have reduced parental linguistic input. It is also possible that the links between motor development and verb – or general word – learning may also vary as a function of the linguistic and social environments that children develop within. Considering these limitations, additional research exploring infant verb comprehension in languages other than English and with representative samples is necessary to corroborate the findings reported in this thesis.

Finally, the research conducted within this thesis has primarily focused on describing *when* infants begin understanding verbs and exploring concurrent correlations with their motor development. These findings give insight into the types of words young infants can understand and when we may typically expect infants to begin understanding them. Such knowledge is important for informing our theories of children’s cognitive development, allowing future research to design studies that can delve into exploring the mechanisms that support such word learning before children become experienced language users. This thesis helps us to constrain potential verb learning mechanisms children may use to acquire verbs by indicating they need to be in place by at least 10 months.

In Chapter 1, I outlined a body of research describing when infants may acquire some of the skills that theorists argue are necessary for verb learning (Gentner, 1978, 2006; Gentner & Boroditsky, 2001; Golinkoff et al., 2002), though additional research is needed to explore if infants indeed exploit these skills to learn verbs. Analogously, in Chapter 1 and 4, I described literature that proposes motor development supports infants’ word learning by creating novel exploration opportunities and that verb learning may occur as parents label infants' bodily actions. The findings from Chapter 4 provide some support that motor development may be important for verb learning, but the correlational nature of this research cannot confirm any causal effects or point to potential mechanisms underpinning this relation. In the following section, I discuss potential avenues for future research that could extend the findings of this thesis and address some of the aforementioned limitations.

5.6. Future Directions

This thesis has identified when infants begin understanding verbs, contributing to a body of work that has begun mapping out the types of words found in the early lexicon and when they are understood (Bergelson & Swingley, 2012, 2013; Tincoff & Jusczyk, 1999, 2012). To best understand children's early receptive language, verb understanding should be further investigated across infancy and early childhood to ascertain verb learning trajectories and norms. This is especially important given that children rarely say the verbs they know (Goldfield, 2000; Huttenlocher et al., 1983; Valleau et al., 2018), making it challenging to assess how many verbs children understand using parent-report measures. Importantly, such investigations should be completed cross-linguistically, as has largely been achieved with parent-report measures of vocabulary (Frank et al., 2017).

As described earlier in this chapter, the focus of this thesis has been to establish the onset of verb understanding during infancy. To build broader theories of word learning, additional work should aim to ascertain the mechanisms that enable infants to understand verbs despite their general limited understanding of abstract concepts. In Chapter 1, I described several theories of word learning that describe possible mechanisms for word learning, including innate biases (Markman, 1990; Nelson, 1988), use of social pragmatic cues (Tomasello, 1992a, 1992b, 1995), associative learning (Samuelson & Smith, 1998; Smith, 2000; Smith et al., 1996), and syntactic bootstrapping (Brown, 1957; Gleitman, 1990; Naigles, 1990). Much of the evidence in support of these theories have come from studies with toddlers or children, with some primarily focusing on noun learning as a model for lexical acquisition. Moreover, some theorists argue that for complex and abstract referents like verbs, it is likely that infants and children likely exploit several interacting mechanisms to learn new words (Childers et al., 2018). As such, more work is needed to understand whether these mechanisms would support the learning of verbs in younger infants and children, and whether these theories can explain the current findings. For example, a recent study with 12-month-olds has demonstrated that infants use mechanisms such as mutual exclusivity and social cues (e.g., pointing) to learn novel object labels, assessed via a looking while listening paradigm (Pomiechowska et al., 2021). Similar designs could be used to explore whether infants can infer the meaning of novel verbs in the presence of social cues (e.g., a novel verb referent being pointed to/accompanied by iconic gestures/gazed at), through the use of syntax (e.g., novel verbs presented in verb frames compared to general exclamative sentences) or exploiting constraints (whether learned or innate) such as mutual exclusivity/novel name-nameless category principles.

Verbs, like other words, are not learned in a void. Children begin learning verbs in their day-to-day life, as they learn to navigate the world both physically and socially. As much research shows, infants' motor development is associated with their word learning. In this thesis, I have demonstrated that this link may be especially important for verb learning, but future research needs to directly test whether infants' bodily actions in some way facilitate verb learning. With noun learning, experimental studies have shown that infants' actions can support their novel noun acquisition in moments of synergy between object holding, visual attention, and object naming from parents (Pereira et al., 2014; Schroer & Yu, 2022; Yu & Smith, 2012). Future studies should aim to relatedly explore this with verb learning. For example, some studies have already shown that young children find imitating actions helpful for learning novel verbs (Gampe et al., 2016). One advantageous strategy to explore this during infancy could be to train infants to perform novel actions (compared to passively observing them) while parents label these actions with novel verbs before testing their verb understanding. In previous research, such experimental designs have been successfully used to explore links between motor experience and neural correlates of action perception and production (Gerson et al., 2015). Indeed, neural systems involved in action processing could also be explored in relation to early verb understanding. That is, embodied approaches of language processing assume that word meanings, especially action-based words, are grounded in our sensorimotor experiences and that neural motor systems may, in part, support word comprehension (Barsalou, 1999, 2008; Glenberg & Gallese, 2012). Therefore, the aforementioned design could also be applied with the view to explore whether the motor system is recruited when infants process verbs, which has already been explored in toddlers and children and thought to support children's verb comprehension (Antognini & Daum, 2019; James & Maouene, 2009).

5.7. Final Conclusions

To build strong word learning theories, it is important to understand what kind of words exist in children's early lexicons, when they began understanding them, and to explore how children come to learn these words. In this thesis, I have found that infants can understand verbs in their first year of life, by at least 10-months-old. However, I also found that verb understanding can be challenging to capture in younger infants as this was only detectable by examining neural correlates associated with word comprehension. One potential helpful source of information for learning about verbs, and words in general, is infants' own bodily actions. By investigating word comprehension and motor development in infants aged 6- to 24-months-old, I showed that motor development is linked with the number of verbs infants understand. Importantly, verb understanding was found to be more strongly linked with motor development than noun understanding during the first two years of life. The research in this thesis has provided insight into the infant lexicon and strengthened our understanding of early linguistic milestones. From here, these findings should be extended to better understand the mechanistic processes that underlie infants' early verb learning.

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Appendix A. Additional parent-report verb items included in the Oxford-CDI

Here, I describe the additional verb items included in the Oxford-CDI in Chapter 4 and where they were selected from. Items were derived either from the MacArthur-Bates Communicative Development Inventory: Actions and Gestures section (Fenson et al., 1994), the MacArthur-Bates Communicative Development Inventory: Phrases section (Fenson et al., 1994), or the Early Motor Questionnaire (Libertus & Landa, 2013). This list also has relevance for Chapter 2 and 3 as I use results from this measure to select items for the looking-while-listening and ERP tasks.

Verb	Measure Derived From
Brush	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Build	Early Motor Questionnaire
Chase	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Clap	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Crawl	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Dig	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Fly	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Lick	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Nod	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Pat	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Point	MacArthur-Bates Communicative Development Inventory: Action and Gestures Early Motor Questionnaire
Pour	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Shake	Early Motor Questionnaire
Sit	Early Motor Questionnaire
Sniff	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Spit	MacArthur-Bates Communicative Development Inventory: Phrases
Talk	MacArthur-Bates Communicative Development Inventory: Action and Gestures
Wave	MacArthur-Bates Communicative Development Inventory: Action and Gestures Early Motor Questionnaire

Appendix B. All action and gestures items included the UK-CDI

Here I provide the list of Action and Gesture items used from the UK-CDI with additional items included to measure infants' ability to perform the actions associated with the verb stimuli in the tasks. Items in the First Communicative Gestures section use response options of "Not Yet", "Sometimes", and "Often". The following items use a response option of "No" and "Yes". The Additional Item column indicates which items were added to the measure, with permission from the authors. The Verb column indicates whether an item was used to measure infants' ability to perform an action associated with a verb in the task and which verb it was linked to.

Action and Gesture Section	**Item**	**Additional Item**	**Verb**
First Communicative Gestures	Extends an arm to show you something she or he is holding.		
	Reaches out and gives you a toy or some object that she or he is holding.		
	When you look/point at toy across the room, does your child look at it?		
	Points (with arm and index finger extended) at some interesting object or event.		
	Waves bye-bye on his or her own when someone leaves.		Wave
	Extends his or her arm upward to signal a wish to be picked up.		
	Shakes head "no".		
	Nods head "yes".		
	Gestures "hush" by placing finger to lips.		
	Requests something by extending arm and opening and closing hand.		
	Blows kisses from a distance.		Kiss
	Shrugs to indicate "all gone" or "where did it go".		
	Gives cuddles.	Yes	Cuddle
Games and Routines	Plays 'peekaboo'/'peepo'.		
	Plays 'pattycake'/ 'pat-a-cake'.		
	Plays chasing games.		

	Sings.		
	Dances.		Dance
	Claps hands.	Yes	Clap
	Plays 'high five'/'gimme five'.		
	Sits up on his or her own.	Yes	Sit
	Plays tickling games.	Yes	Tickle
	Walks WITH support.	Yes	Walk
	Walks WITHOUT support.	Yes	Walk
Actions with Objects	Eat with a spoon or fork, holding or helping to hold the spoon or fork.		
	Drink from an open cup containing liquid.		Drink
	Comb or brush own hair.		
	Brush teeth.		
	Wipe face or hands with a towel or cloth.		
	Put on a hat.		
	Put on a shoe or a sock.		
	Put on a necklace, bracelet, or watch.		
	Lay head on hands and squeeze eyes shut as if sleeping.		
	Blow to indicate something is hot.		
	Hold plane and make it "fly".		
	Put telephone to ear.		
	Sniff flowers.		
	Push toy car or truck.		
	Throw a ball.		
	Pour pretend liquid from one container to another.		
	Stir pretend liquid in a cup or pan with a spoon.		
	Pretend to 'drink' from a cup or other object.		Drink
	Bites on food or on toys/objects.	Yes	Bite
Pretending To Be a Parent	Put to bed.		

Cover with blanket.
Feed with bottle or at the breast.
Feed with spoon.
Brush/comb its hair.
Push in pram/buggy.
Rock it.
Kiss or hug it.
Try to put shoe, sock or hat on it.
Wipe its face or hands.
Talk to it.
Try to put nappy on it.
Sweep with a broom or mop.
Put a key in a door or lock.
Bang with a hammer or mallet.
Attempt to use a saw.
"Type" at a typewriter or computer keyboard.
"Read" (opens book, turns page).
Hoover.
Play a musical instrument (e.g. piano, trumpet).
"Drive" a car by turning steering wheel.
Washing up / wash dishes.
Clean with a cloth or duster.
Write with a pen, pencil, or marker.
Dig with a spade.
Put on glasses.

Appendix C. Pre-labelling bias correction verb comprehension analyses

As described in Chapter 2, looking while listening paradigms often use computations that correct for infants' stimulus preference. The analyses described in across Chapter 2 utilised a *post-label correction.* In contrast, the *pre-label correction* involves taking the proportion of time looking at a stimulus during a test trial, minus the proportion of time looking at the same stimulus either during a familiarisation trial or a period prior to the target word being spoken (e.g., Bergelson & Aslin, 2017; Nomikou et al., 2019). Pre-label corrections create a score for each word item and results in scores between -1 and 1, with scores greater than zero indicating fixating longer on the target stimulus. The following analyses replicate those exploring verb comprehension in the looking while listening task (Chapter 2) but using a *pre-label correction* instead. For analyses using the *pre-labelling correction*, infants were required to contribute at least 6 or more verb items (equal to or greater than 60% of verbs) to be kept in the analysis.

Study 1: 10-month-olds

For 10-month-olds infants, 13/22 (59.1%) had positive average looking scores over participants and verb pairs. Analyses of 10-month-olds fixations, over participants and verb pairs, revealed that infants did not look significantly longer at the target item, *Mdn* = 0.006, 95% CI [-0.02, ∞], $p = .305$, $r = .114$, 95% CI [.004, .53].

Ten-month-olds had average positive looking scores, across infants, for 4/10 verb items. Missing looking scores were evenly spread across analyses. The *cuddle, drink, kiss, sit,* and *walk* items had missing data for 1 infant. All infants contributed a looking score to *bite, clap, dance, tickle,* and *wave.*

At this age, infants looked significantly longer at the target item for the *drink* item (*Mdn* = 0.058, 95% CI [0.0001, ∞], $p = .048$, $r = .368$, 95% CI [.03, .74]) and looked marginally longer at the target for the *walk* item (*Mdn* = 0.044, 95% CI [-0.01, ∞], $p = .074$, $r = .322$, 95% CI [.02, .72]). For *drink*, 14/21 (66.7%) infants had positive looking scores and *walk* had 15/21 (71.4%).

Infants also had positive average looking scores for *bite* (12/22, 54.5%), *kiss* (9/21, 42.8%), and *wave* (11/22, 50%) but analyses did not reach significance: (*bite: Mdn* = 0.058, 95% CI [-0.03, ∞], $p = .194$, $r = .190$, 95% CI [.01, .61]), (*kiss: Mdn* = -0.010, 95% CI [-0.09,

∞], *p* = .596, *r* = .053, 95% CI [.01, .53]), and (*wave: Mdn* = 0.021, 95% CI [-0.07, ∞], *p* = .339, *r* = .093, 95% CI [.004, .52]), respectively.

For all other item pairs (*clap, cuddle, dance, sit,* and *tickle*), infants did not look significantly longer at the target item: (*clap*: *Mdn* = -0.067, 95% CI [-0.16, ∞], *p* = .840, *r* = .211, 95% CI [.02, .59]), (*cuddle*: *Mdn* = -0.059, 95% CI [-0.11, ∞], *p* = .952, *r* = .372, 95% CI [.04, .74]), (*dance*: *Mdn* = -0.020, 95% CI [-0.11, ∞], *p* = .649, *r* = .080, 95% CI [.01, .46]), (*sit*: *Mdn* = -0.043, 95% CI [-0.12, ∞], *p* = .813, *r* = .193, 95% CI [.01, .60]), and (*tickle*: *Mdn* = -0.0211, 95% CI [-0.12, ∞], *p* = .672, *r* = .093, 95% CI [.01, .50]), respectively. For these items, only 8/22 (36.4%) infants had positive looking scores for the *clap* item, 5/21 (23.8%) for *cuddle*, 12/22 (54.5%) for *dance*, 8/21 (38.1%) for *sit*, and 10/22 (45.5%) for *tickle*.

Study 1: 14-month-olds

For 14-month-olds infants, 13/18 (72.2%) had positive average looking scores over participants and verb pairs. Analyses of 14-month-olds fixations, over participants and verb pairs, revealed that infants looked significantly longer at the target item (*Mdn* = 0.041, 95% CI [0.01, ∞], *p* = .024, *r* = .467, 95% CI [.07, .83]).

Fourteen-month-olds had average positive looking scores, across infants, for 8/10 verb items. Missing looking scores were mostly evenly spread across analyses. The *dance, drink, walk,* and *wave* items had missing data for 1 infant. All infants contributed a looking score to *bite, clap, cuddle, kiss, sit,* and *tickle.*

At this age, there was a marginal effect for the *clap* item (*Mdn* = 0.127, 95% CI [0.01, ∞], *p* = .059, *r* = .375, 95% CI [.03, .73]) and for the *walk* item (*Mdn* = 0.117, 95% CI [-0.01, ∞], *p* = .060, *r* = .385, 95% CI [.03, .75]). For *clap*, 11/18 (61.1%) infants had positive looking scores and *walk* had 12/17 (70.6%).

Infants also had positive average looking scores for *kiss* (9/18, 50%), *tickle* (10/18, 55.6%), *wave* (11/17, 64.7%) and *drink* (10/17, 58.8%) but analyses did not reach significance: (*kiss: Mdn* = 0.027, 95% CI [-0.09, ∞], *p* = .352, *r* = .092, 95% CI [.01, .56]), (*tickle: Mdn* = 0.037, 95% CI [-0.04, ∞], *p* = .305, *r* = .128, 95% CI [.01, .57]), (*wave: Mdn* = 0.081, 95% CI [-0.02, ∞], *p* = .112, *r* = .304, 95% CI [.02, .74]), and (*drink: Mdn* = 0.044, 95% CI [-0.06, ∞], *p* = .274, *r* = .155, 95% CI [.01, .63]).

For all other item pairs (*bite, cuddle, dance,* and *sit*), infants did not look longer, on average, at the target item: (*bite*: *Mdn* = -0.001, 95% CI [-0.14, ∞], *p* = .517, *r* = .005, 95%

CI [.01, .52]), (*cuddle*: *Mdn* = -0.038, 95% CI [-0.18, ∞], p = .649, r = .087, 95% CI [.01, .53]), (*dance*: *Mdn* = -0.011, 95% CI [-0.11, ∞], p = .609, r = .063, 95% CI [.01, .56]), and (*sit*: *Mdn* = -0.023, 95% CI [-0.11, ∞], p = .695, r = .118, 95% CI [.01, .56]), respectively. For these items, only 10/18 (55.6%) infants had positive looking scores for the *bite* item, 9/18 (50%) for *cuddle*, 7/17 (41.2%) for *dance*, and 8/18 (44.4%) for *sit*.

Study 2: 10-month-olds

For 10-month-olds infants, 16/30 (53.3%) had positive average looking scores over participants and verb pairs. Analyses of 10-month-olds fixations, over participants and verb pairs, revealed that infants did not look significantly longer at the target item, *Mdn* = -0.010, 95% CI [-0.04, ∞], p = .749, r = .122, 95% CI [.01, .44].

Ten-month-olds had average positive looking scores, across infants, for 3/10 verb items. Missing looking scores were evenly spread across analyses. The *cuddle* item had missing data for 7 infants. The *drink* item had missing data for 6 infants. The *walk* item had missing data for 5 infants. The *kiss* and *dance* items had missing data for 3 infants. The *clap* item had missing data for 4 infants. The *tickle* and *bite* items had missing data for 2 infants. The *wave* item had missing data for 1 infant. All infants contributed a looking score to *sit.*

For the *wave* item, 19/29 (65.5%) infants had positive looking scores. Infants looked marginally longer at the target item for the *wave* item (*Mdn* = 0.069, 95% CI [-0.02, ∞], p = .072, r = .275, 95% CI [.01, .58]). *Drink* and *dance* also had average positive looking scores with 13/24 (54.2%) looking larger at the target for the *drink* item and 17/27 (62.9%) for the *dance* item. However, these scores were not significantly different from zero (*drink: Mdn* = 0.016, 95% CI [-0.068, ∞], p = .322, r = .099, 95% CI [.006, .51], *dance*: *Mdn* = 0.028, 95% CI [-0.077, ∞], p = .393, r = .056, 95% CI [.009, .47]). For all other items, infants' target looking was also at chance (*bite: Mdn* = -0.008, 95% CI [-0.080, ∞], p = .562, r = .028, 95% CI [.007, .46], *clap: Mdn* = -0.144, 95% CI [-0.222, ∞], p = .996, r = .513, 95% CI [.19, .77], *cuddle: Mdn* = -0.004, 95% CI [-0.073, ∞], p = .530, r = .013, 95% CI [.006, .46], *kiss: Mdn* = -0.128, 95% CI [-0.207, ∞], p = .994, r = .499, 95% CI [.19, .76], *sit: Mdn* = -0.009, 95% CI [-0.068, ∞], p = .590, r = .047, 95% CI [.01, .43], *tickle: Mdn* = -0.058, 95% CI [-0.104, ∞], p = .963, r = .338, 95% CI [.03, .66], *walk: Mdn* = -0.009, 95% CI [-0.093, ∞], p = .614, r = .056, 95% CI [.008, .48]). Thirteen out of 28 (46.4%) infants had positive looking scores for the *bite* item, 7/26 (26.9%) for *clap,* 10/23 (43.5%) for *cuddle*, 5/27 (18.5%) for *kiss*, 12/30 (40%) for *sit*, 9/28 (32.1%) for *tickle,* and 10/25 (40%) for *walk.*

Appendix D. Correlations between target looking and vocabulary measures

Here, I include the correlation coefficients (Spearman Rank) and exact p-values from **Chapter 2.5.3.2.**

	Whole UK-CDI		Verbs UK-CDI		Verbs in the task	
	Comprehends	Says	Comprehends	Says	Comprehends	Says
10-months	$r_s = -.11$, $p = .659$	$r_s = -.23$, $p = .340$	$r_s = -.32$, $p = .167$	-	$r_s = -.17$, $p = .482$	-
14-months	$r_s = .16$, $p = .547$	$r_s = .37$, $p = .144$	$r_s = .24$, $p = .349$	$r_s = .22$, $p = .395$	$r_s = .28$, $p = .276$	$r_s = .31$, $p = .232$
All infants	$r_s = .17$, $p = .303$	$r_s = .18$, $p = .299$	$r_s = .08$, $p = .642$	-	$r_s = .13$, $p = .444$	-

Appendix E. N400 ANOVA including hemisphere as a within-subjects factor

A three-way repeated measures ANOVA was conducted with condition (congruent verb | incongruent verb), region (frontal | central | parietal) and hemisphere (left, midline, right) as within-subject factors. The analysis revealed a significant main effect of brain region, $F(1.57, 40.71) = 17.66$, $p < .001$, $\eta_p^2 = .40$. Follow-up tests revealed that, across conditions, frontal mean amplitudes were significantly greater than those in the central (*Mdiff* = -4.55, $t(52) = -3.93$, $p < .001$) and parietal regions (*Mdiff* = -6.75, $t(52) = -5.83$ $p < .001$). The main effects of condition and hemisphere were not significant.

There was also a near significant condition by region interaction, $F(1.85, 48.18) = 3.22$, $p = .052$, $\eta_p^2 = .11$. In the frontal region only, incongruent verbs evoked amplitudes that were significantly more negative than for congruent verbs (*Mdiff* = 1.67, $t(76.5) = 2.05$, $p = .044$). No differences in amplitude between incongruent or incongruent trials were detected in central (*Mdiff* = -0.73, $t(76.5) = -0.89$, $p = .377$) or parietal regions (*Mdiff* = -0.75, $t(76.5) = -0.92$, $p = .359$).

There was also a significant region by hemisphere interaction, $F(2.94, 76.39) = 5.53$, $p = .002$, $\eta_p^2 = .18$. Follow up tests revealed that in the left hemisphere, frontal mean amplitudes were significantly greater than those in the parietal region (*Mdiff* = -6.54, $t(91.4) = -4.82$, $p < .001$). In the midline, frontal mean amplitudes were significantly greater than those in the parietal (*Mdiff* = -8.05, $t(91.4) = -5.94$, $p < .001$) and central regions (*Mdiff* = -7.80, $t(91.4) = -5.75$, $p < .001$). In the right hemisphere, frontal mean amplitudes were significantly greater than those in the parietal region (*Mdiff* = -5.66, $t(91.4) = -4.18$, $p < .001$).

Appendix F. N400 ANOVAs including vocabulary as between-subjects factors

Comprehension Scores as Between Subjects Factor

A three-way repeated measures ANOVA was conducted with condition (congruent verb | incongruent verb) and region (frontal | central | parietal) as within-subject factors and vocabulary comprehension (low | high) as a between-subjects factor. The analysis revealed a significant main effect of brain region, $F(1.57, 39.23) = 17.21$, $p < .001$, $\eta_p^2 = .41$. Follow-up tests revealed that, across conditions, frontal mean amplitudes were significantly greater than those in the central (*Mdiff* = -4.55, $t(52) = -3.93$, $p < .001$) and parietal regions (*Mdiff* = -6.75, $t(52) = -5.83$ $p < .001$). The main effects of condition and vocabulary comprehension were not significant.

There was also a near significant condition by region interaction, $F(1.86, 46.44) = 3.23$, $p = .052$, $\eta_p^2 = .11$. In the frontal region only, incongruent verbs evoked amplitudes that were significantly more negative than for congruent verbs (*Mdiff* = 1.71, $t(73.8) = 2.08$, $p = .041$). No differences in amplitude between incongruent or incongruent trials were detected in central or parietal regions.

Production Scores as Between Subjects Factor

A three-way repeated measures ANOVA was conducted with condition (congruent verb | incongruent verb) and region (frontal | central | parietal) as within-subject factors and vocabulary production (low | high) as a between-subjects factor. The analysis revealed a significant main effect of brain region, $F(1.56, 38.96) = 16.55$, $p < .001$, $\eta_p^2 = .40$. Follow-up tests revealed that, across conditions, frontal mean amplitudes were significantly greater than those in the central (*Mdiff* = -4.55, $t(52) = -3.93$, $p < .001$) and parietal regions (*Mdiff* = -6.75, $t(52) = -5.83$ $p < .001$). The main effects of condition and vocabulary production were not significant.

There was also a significant condition by region interaction, $F(1.87, 46.63) = 3.59$, $p = .038$, $\eta_p^2 = .13$. In the frontal region only, incongruent verbs evoked amplitudes that were significantly more negative than for congruent verbs (*Mdiff* = 1.79, $t(73.2) = 2.17$, $p = .034$). No differences in amplitude between incongruent or incongruent trials were detected in central or parietal regions.

Appendix G. GLMM random structure model selection

To establish the random structure of the GLMM, three models were established; (a) maximal random structure (described in the main text), (b) a random intercept only model, and (c) a simple random slope model. The model structure of (b) and (c) were as follows:

(b) Word Comprehension ~ EMQ Score* Word Type + Age + (1 | Infants) + (1 | Word Items)

(c) Word Comprehension ~ EMQ Score* Word Type + Age + (1 + Word Type | Infants) + (1 | Word Items)

Following estimation, each model containing random slopes was compared against the random intercept only model using a Chi Square difference test χ^2. Both models significantly improved the model fit. As such, the model with the lowest AIC (Akaike Information Criterion), a descriptive parameter of model fit, was selected (i.e., maximal random effect structure). See the following table for details.

Model	AIC	BIC	Loglik	Deviance	χ^2	df	*p*-value
Random Intercepts	26254	26314	-13120	26240			
One Random Slope	25927	26004	-12954	25909	331.38	2	<.001
Maximal Structure	25779	25899	-12876	25751	489.06	7	<.001

Appendix H. Word comprehension and gross/fine motor skills

In the main text, links between motor skills and vocabulary were explored using total EMQ scores. Here, I report equivalent analyses with gross and fine motor skills as predictors. Statistical significance was assessed at an α of .05 and Bonferroni corrections were applied to *p*-values to correct for multiple comparisons. As in the main text, preliminary analyses, correlational (including partial correlations), and logistic mixed effect models are reported.

Associations between infants' age and gross motor scores and fine motor scores were explored. A strong positive correlation emerged between age and EMQ scores (see Figure 4.1; $r_s = .90$, $p < .001$). Age was also positively associated with infants' gross motor scores and fine motor scores, ($r_s = .85$, $p < .001$, $r_s = .86$, $p < .001$), respectively. These associations show that, as would be expected, motor development and vocabulary development is strongly related to infants' age. As such, age will be controlled for in all subsequent analyses.

To test associations between infants' gross and fine motor skills and their verb and noun vocabulary, correlations were performed. An additional correlation was performed to examine the relation motor skills and infants' total CDI comprehension scores to replicate findings from previous literature. Subsequent partial correlations were conducted to control for age. Correlations revealed strong positive correlations between gross motor skills and verb comprehension scores ($r_s = .83$, $p < .001$), noun comprehension scores ($r_s = .73$, $p < .001$), and total comprehension scores ($r_s = .73$, $p < .001$). Similarly, correlations revealed strong positive correlations between fine motor skills and verb comprehension scores ($r_s = .79$, $p < .001$), noun comprehension scores ($r_s = .81$, $p < .001$), and total comprehension scores ($r_s = .81$, $p < .001$). However, only associations with fine motor scores remained significant after controlling for age. Partial correlations revealed significant positive associations between fine motor skills and verb comprehension scores ($r_s = .36$, $p = .005$), noun comprehension scores ($r_s = .40$, $p = .001$), and total comprehension scores ($r_s = .39$, $p < .002$). All partial correlations with gross motor scores were non-significant; verb comprehension scores ($r_s = .17$, $p = .707$), noun comprehension scores ($r_s = .15$, $p = 1$), and total comprehension scores ($r_s = .14$, $p = 1$). Please note *p*-values here equal 1 after multiple comparison correction.

To assess whether the association between each motor skill subtype and word comprehension is stronger for verbs over nouns, I fit a binomial generalized linear mixed-effect model (GLMM) with a logit link function (i.e., a logistic mixed effect model). The same model selection process and structure used in the main text was applied for these models. Gross and fine motor skills were included in separate models. For both, the same maximal model structure described in the main text (replacing total EMQ scores) was applied as they significantly improved the model fit. The gross motor model and fine motor model are described in turn.

The gross motor model revealed a significant interaction between motor skills and word type (B = -0.35, CI 95% [-0.61,-0.08], SE = 0.14, z = -2.57, p =. 010). This interaction was followed up with the *emtrends*() and *pairs*() functions from the *emmeans* package (Lenth, 2021). As with the model in the main text, results showed that the association between word comprehension and gross motor skills was significantly greater for verbs (B = 0.021, CI 95% [0.003,0.034], SE = 0.01) than for nouns (B = 0.012, CI 95% [-0.005,0.029], SE = 0.009), (B = 0.009, CI 95% [0.002,0.015], SE = 0.003, z = 2.57, p =. 010). A significant main effect of word type emerged (B = -0.91, CI 95% [-1.49,-0.33], SE = 0.30, z = -3.09, p =. 002). Thus, the average infant in the sample understood a greater proportion of verbs than they did nouns. An additional main effect of age emerged (B = 1.69, CI 95% [-0.07,1.51], SE = 0.35, z = 4.89, p <.001), suggesting that word comprehension increased with age. The main effect of gross motor skills on word comprehension was marginal (B = 0.67, CI 95% [-0.03,1.37], SE = 0.36, z = 1.87, p = .058).

The fine motor model revealed a significant interaction between motor skills and word type (B = -0.37, CI 95% [-0.65,-0.09], SE = 0.14, z = -2.60, p =. 009). This interaction was followed up with the *emtrends*() and *pairs*() functions from the *emmeans* package (Lenth, 2021). As with the model in the main text, results showed that the association between word comprehension and fine motor skills was significantly greater for verbs (B = 0.06, CI 95% [0.035,0.089], SE = 0.013) than for nouns (B = 0.048, CI 95% [-0.005,0.029], SE = 0.013), (B = 0.014, CI 95% [0.003,0.025], SE = 0.005, z = 2.60, p =. 009). There was also a significant main effect of fine motor skills on word comprehension, with the likelihood of understanding a word increasing with greater fine motor skills (B = 1.45, CI 95% [0.79,2.11], SE = 0.34, z = 4.29, p <. 001). As above, a significant main effect of word type emerged (B = -0.91, CI 95% [-1.47,-0.35], SE = 0.29, z = -3.20, p =. 001) following the same pattern. Further, a main effect of age emerged (B = 1.06, CI 95% [0.41,1.70], SE = 0.33, z = 3.22, p = .001), suggesting that word comprehension increased with age.