Development of Spatial Language and Memory: Effects of Language Modality and Late Sign Language Exposure

Dilay Z. Karadöller

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Dedicated to my beloved son, Ata...

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Chapter 1: General Introduction

Children from very early on observe and act on the objects around them. These objects are often configured in various spatial relations to each other. Reasoning and communicating about spatial relations are among the fundamental abilities that children need to develop. The current thesis investigates the question of how children develop the ability to communicate and reason about spatial relations and which factors influence this development.

Many scholars acknowledge that the development of spatial language is the outcome of the development of cognitive understanding of spatial relations, on the one hand, and the linguistic ways to express spatial relations, on the other. Some scholars argue for a stronger role of cognitive understanding of spatial relations shaping spatial language development by showing that language builds on and reflects spatial concepts that developed prior to and independent of language (e.g., Clark, 2004; Johnston, 1985, 1988). For example, studies conducted with various languages presented evidence that locative spatial terms are learned at predictable ages and in a predictable order in different spoken languages (e.g., use of spatial terms such as *In-On-Under* preceding *Left-Right*), which indicates a strong role of nonverbal cognitive development of space determining spatial language development (e.g., Clark, 2004; Johnston & Slobin, 1979; Piaget & Inhelder, 1971; Tomasello, 1987). Some others argue for a role of linguistic factors also shaping spatial language development rather than merely reflecting nonverbal cognitive development of spatial relations. This is based on evidence that children tune into language-specific variation in their language input early on (e.g., Allen et al., 2008; Bowerman, 1996a, 1996b; Bowerman & Choi, 2001; Choi & Bowerman, 1991). For example, children learn to encode language-specific aspects of spatial configurations very early on. For example, “tight fit” versus “loose fit” distinctions between two objects that are in a containment type of spatial relationship are encoded differently in Korean but not in English. Korean children can learn to talk about these distinctions very early on. Thus, in this latter view, children can structure their semantic and cognitive understanding of space through language-specific constraints (e.g., semantic, morphological, syntactic, etc.) as well as cognitive ones.

Furthermore, linguistic representations of space are considered to have consequences on other aspects of spatial cognition, such as memory for spatial relations. Scholars argue that knowledge and use of spatial terms enhance memory for spatial relations (Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Loewenstein & Gentner, 2005; Landau et al., 2011; Miller et al., 2016; Shusterman et al., 2011; Simms & Gentner, 2019). Some of these studies have provided evidence for a positive correlation between children's use of specific spatial terms such as *Left-Right* (Hermer-Vasquez et al., 2001) and *Middle* (Simms & Gentner, 2019) and their spatial memory performance. Other studies have provided experimental evidence showing that providing children with spatial terms (Dessalegn & Landau, 2008; Lowenstein & Gentner, 2005) increased their accuracy in a spatial memory task.

In all of the above-mentioned studies, however, the nature of the interplay between spatial language and cognition has been investigated by focusing mostly on spoken languages and on hearing children who have immediate access to language. Yet, there is little known whether other possible variations in language acquisition situations modulate the interplay between spatial language and cognition. One of these variations is the modality of language children are exposed to, which can be construed as a language specific factor. Deaf children acquire sign languages that are expressed in the visual-spatial modality (see Lillo-Martin & Henner, 2021 for a recent review). Speaking children observe co-speech gestures in their language input and also acquire them along with speech in a way specific to their spoken languages (e.g., Özyürek et al., 2008; Özyürek, 2018 for a review). However, to date little is known whether variation in language modality; that is using speech, sign, or co-speech gestures, can shape the development of spatial language differently for signers and speakers. Unlike in speech, visual-spatial modality of expression as in sign and co-speech gestures allows iconic expressions of spatial relations that might modulate the development of spatial language and give unique insights about the interplay between development of spatial language and cognition.

Another type of variation in language development concerns the timing of exposure to a conventional language as in the case of deaf children. The majority of deaf children are born to hearing parents (Mitchell & Karchmer, 2004). In such cases, exposure to a sign language can be quite late (e.g., in school context after age 6) (see Lillo-Martin & Henner, 2021; Mayberry, 1998; Mitchell & Karchmer, 2004), especially in countries where there are no preschools for the deaf such as in Turkey (İlkbaşaran, 2015). Yet, prior work on spatial language development is largely based on data from hearing or deaf children who are exposed to a spoken/signed language immediately following birth and neglects a group of deaf children who have hearing parents and are exposed to a conventional language late (i.e., late signers). Investigating linguistic development of space in late signing children in comparison to deaf children who are exposed to a sign language since birth by signing deaf parents (i.e., native signers)[1] can reveal novel insights about the development of relation between spatial language and cognition. For example, if development of cognitive representations of space is the stronger factor and if language merely maps onto these representations, late signing children might be on a par with their native signing peers in spatial language use even after a short time of exposure to language. However, if linguistic factors play a major role in development of cognitive representations of space, late signing children might lag behind their native signing peers in spatial language use and the hindering effect of late language exposure might even last into their adulthood.

Finally, it is not known whether the effects of variation in language modality or variation in language use as a result of late language exposure can modulate the previously found relations between spatial language and memory for spatial relations (e.g., Dessalegn & Landau, 2008; Gentner, 2016; Landau et al., 2011; Lowenstein & Gentner, 2005). So far, only a few studies have addressed these issues. Some of these studies have looked at the effect of encoding space in speech alone or in gesture alone on memory for spatial relations in hearing children (Abarbanell & Li, 2021; Miller et al., 2016). Others have tested whether or not having a language exposure predicts memory for space by comparing deaf children without language exposure to speaking children (i.e., Gentner et al., 2013). It is possible to think that using iconic forms of spatial relations in sign or gesture accompanying speech might facilitate memory for spatial relations or late exposure to language might hinder facilitating effects of using language on memory as found in previous research.

[1] Following several scholars (e.g., Lillo-Martin & Henner, 2021; Mayberry, 1998; Newport, 1990), we use the term *native* to refer deaf individuals who have a sign language exposure immediately following birth from their signing deaf parents. We use the term *late* to refer to deaf individuals who have a sign language exposure later in their life. In the sample reported in the current thesis, all late signers were first exposed to sign language after age of 6.

Therefore, the current thesis aims to go beyond previous work to contribute to our understanding of the relationship between spatial language and cognition in development. To do so, it introduces variation in *language modality* and *timing of sign language exposure* as new angles to study this relationship by asking three main research questions. These questions are investigated in detail in four different empirical studies reported in **Chapters 2 to 5**:

(RQ1) Does the variation in language modality as in speech, sign, and co-speech gestures modulate how children use spatial language?

(RQ2) Does the variation in the timing of language exposure modulate using spatial language in the case of deaf late and native signers?

(RQ3) Do modality of language use (investigated in RQ1) and the timing of language exposure (investigated in RQ2) influence subsequent memory for spatial relations?

To investigate these questions, the current thesis uses data elicited from child and adult hearing speakers of Turkish as well as child and adult deaf signers of Turkish Sign Language (*Türk İşaret Dili* [TİD]) residing in Istanbul. TİD is the conventional sign language of the deaf community in Turkey (e.g., Arık, 2016; İlkbaşaran, 2015; Kubuş, 2008; Sümer, 2015; see also Box 1.1. for the historical background of TİD and Box 1.2. for the current educational curriculum in the deaf schools of Turkey). Hence, the empirical research reported here provides a cross-linguistic and a multimodal perspective to previous research conducted concerning the development of spatial language use and its relations to cognition. In doing so, it specifically focuses on the domain of locative spatial relations (i.e., spatial relation between two static objects) as this is a domain in which most previous work has been conducted, including Turkish and TİD (e.g., Arık, 2013; Perniss et al., 2015a; Sümer, 2015; Sümer & Özyürek, 2020; Sümer et al., 2014). This focus allows building on prior literature more directly. Furthermore, within locative relations, our main empirical focus is Left-Right spatial relations (e.g., the pen is to the *left* of the paper) that have been found to be a late aspect of acquisition due to their cognitive complexity (e.g., Clark, 2004; Johnston, 1895) (please see section 1.1.1. for more details).

The first research question (RQ1) focuses on the variation in *language modality* to explore the relation between linguistic and cognitive development of spatial relations. This investigation builds on the fact that visual-spatial forms that encode space (i.e., sign and co-speech gestures) differ fundamentally from the forms in auditory-vocal modality (i.e., speech). Sign languages incorporate visual-spatial articulators that allow for visually motivated meaning mappings (i.e., iconic and analogue) between the linguistic form and its referent in the real space to encode spatial relations between objects (e.g., Emmorey, 2002; Perniss, 2007; also see section 1.1.2.2. and Figures 2 and 3 below). By contrast, the auditory-vocal nature of speech in spoken languages does not allow for such visually motivated form-meaning mappings of spatial relations but incorporates linguistic forms that have arbitrary mappings to the spatial relations they encode. In spoken languages, co-speech gestures also allow for visually motivated form-meaning mappings in expressing spatial relations (Kita & Özyürek, 2003; McNeill, 1992; see section 1.1.2.3 and Figure 4 below). The current thesis aims to capture these iconic aspects of communication in sign as well as in co-speech gestures in understanding the development of spatial language use and its relation to spatial cognition. In doing so, it does not only focus on the comparison across sign and speech as most previous work does (e.g., Sümer, 2015; Sümer & Özyürek, 2020; Sümer et al., 2014) but also takes into account co-speech gestures. To do so, it compares sign to speech and to speech-gesture combinations. In this way, it takes a comprehensive approach to investigate development of spatial expressions in sign and spoken languages by incorporating both the auditory-vocal and visual-spatial forms of encoding in the latter (see Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019 for reviews).

Considering the visual-spatial forms of encoding space is crucial for understanding the role of cognitive and linguistic aspects shaping spatial language development. That is, whether children are mainly guided by universal principles of cognitive development about space (e.g., Clark, 2004, Johnston, 1985, 1988) and/or by language-specific encoding possibilities in their languages (e.g., Bowerman, 1996a, 1996b). Multimodal variation in language input might be one of the "language-specific" encoding possibilities that might interact with cognitive development. For example, children might learn to encode Left-Right relations earlier in sign or co-speech gestures than in speech due to iconic encoding possibilities of the visual-spatial forms. Hence, investigating variation in *language modality* enables us to go beyond previous work in understanding whether variation in linguistic encoding possibilities is a medium to shape the development of spatial language use beyond the influence of cognitive development of space. This is the topic of **Chapter 2.**

Regarding the second research question (RQ2), the current thesis focuses on variation in the *timing of language exposure* to explore the role of linguistic and cognitive factors shaping the development of spatial relations by comparing spatial language use of child and adult late signers to their native signing peers. This focus may help investigate the relationship between cognitive and linguistic development of space in yet another novel way. For instance, if cognitive representations of space can develop in the absence of language exposure, late signers will map spatial language onto these representations upon exposure and have comparable linguistic expressions to those of their native signing peers, shortly after language exposure. Alternatively, if cognitive representations of space cannot develop fully in the absence of language, late sign language exposure might have detrimental effects on the spatial language use of late signers compared to native signers. Therefore, focusing on late versus early sign language exposure allows going beyond the previous work by providing unique insights into the roles of linguistic and cognitive factors involved in spatial language development. Here, we also compare learning to encode cognitively simpler spatial relations (i.e., In-On-Under) to cognitively complex ones (i.e., Left-Right) to see whether cognitive complexity of the spatial relations to be encoded further modulates the relationship between linguistic and cognitive development of spatial relations in late and native signers. This is the topic of **Chapter 3**.

While RQ1 and RQ2 focus on variations in language modality and timing of language exposure to investigate the linguistic and cognitive development of spatial language, RQ3 focuses on whether these variations influence the relationship between spatial language use and its consequences for the subsequent memory of spatial relations. Prior work has shown that providing children with spatial terms (e.g., *Left*) that highlight spatial features of target scenes improved memory for these scenes when tested immediately after the presentation of the scenes (Dessalegn & Landau, 2008). Moreover, providing children with spatial terms (e.g., *Middle*) before the experiment by the experimenters themselves resulted in better memory for spatial locations shortly after or even after two days (Lowenstein & Gentner, 2005).

Furthermore, few other studies provided evidence that training children to use specific spatial terms or prompting them to use spatial gestures to solve a task improves performance accuracy (Abarbanell & Li, 2021; Miller et al., 2016). The current thesis investigates whether the variation in the modality of language encoding (i.e., sign, speech, and speech-gesture combinations) as well as the timing of sign language exposure (i.e., late versus early exposure to a sign language) can modulate the relationship between spatial language use and later spatial memory accuracy for both adults and children. It also asks, going beyond previous research, whether encoding the spatial relation between the objects spontaneously produced by children *themselves* promotes higher spatial memory. This investigation goes beyond the relationship between language and cognition merely from a developmental perspective (as investigated by RQ1 and RQ2) and allows to explore spatial language use and its consequences on subsequent memory for spatial relations. RQ3 is the topic of **Chapters 4** (considering the variation in language modality) and **5** (considering the timing of language exposure).

Summarizing, the current thesis focuses on variation in language modality and variation in the timing of sign language exposure as two new angles to study the relationship between spatial language use and cognition. In the remainder of this chapter, there will be a general Literature Review (1.1.). This review will first introduce the domain of Locative Spatial Relations and specifically Left-Right relations (1.1.1.) as the empirical focus of the four experimental studies presented in **Chapters 2 to 5** as well as linguistic encoding of space across languages and modalities (1.1.2.). Next, there will be a review of the previous literature on the Development of Spatial Language Use (1.1.3.) and the Relation between Spatial Language and Spatial Memory (1.1.4.) taking into account what we already know about the effects of language modality and late sign language exposure on the relation between development of spatial language and cognition. At the end of this literature review, The Present Thesis section (1.2.) will introduce the general research questions of the empirical chapters and the general methodology employed in these chapters to answer these questions. Finally, the current chapter ends with an overview of the empirical chapters concerning the main predictions of the current thesis (1.2.3.).

1.1. Literature Review

1.1.1. Locative Spatial Relations: A Domain to Study the Development of Spatial Language Use and Its Relations to Spatial Cognition

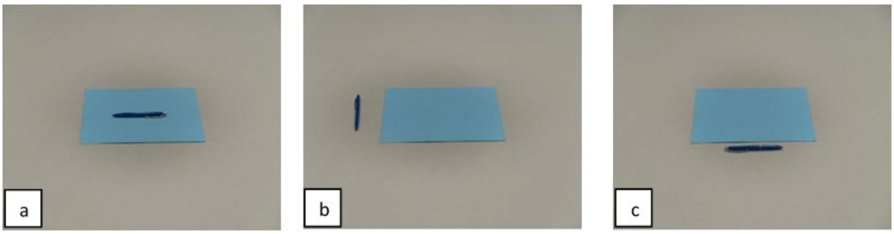
The concept of "space" is semantically defined as a domain that typically refers to the location and motion of referents with respect to other referents (Talmy, 1985). Linguistically, this domain provides answers to “where-questions" (Levinson, 1996). The current thesis focuses on locative spatial relations between objects (e.g., *the pen is to the left of the paper*; Figure 1b) as the empirical testbed to investigate spatial language and its relation to spatial cognition in development.

The linguistic encoding of the locative spatial relations requires the mention of Figure (e.g., pen) and Ground (e.g., paper) objects as well as their spatial relation with respect to each other. The Figure is traditionally known as the smaller and foregrounded object which is located with respect to a backgrounded, bigger, and relatively less mobile object known as the Ground (Talmy, 1985). With regard to the linguistic encoding of the spatial relation between these objects, one of the distinctions is whether or not this encoding requires the viewpoint of the observer. Objects that are coincided in the same location (e.g., objects that bear contact/support type of relationship as in Figure 1a) do not require an observer’s viewpoint (Landau, 2017). By contrast, objects that are coincided remotely with each other (i.e., objects that bear an angular relationship; as in Figure 1b and Figure 1c) require observers to take a viewpoint (see Landau, 2017 for a review).

Viewpoint-dependent spatial relations (Figure 1b and Figure 1c) require further classifications as they seem to denote symmetrical spatial layouts (Left versus Right and Front versus Behind). Nevertheless, the case of Front-Behind can be distinguished by notions of visibility (in the case of Front) and occlusion (in the case of Behind). These notions provide an asymmetrical relationship between Front and Behind (see Grigoroglou et al., 2019 for a discussion). Therefore, Front can be distinguished from Behind. By contrast, Left-Right remains to be symmetrical as there are no cues to distinguish them from one another, especially in the case of Grounds without intrinsic features (e.g., a car has an intrinsic Front and Behind but a plate does not). As a result, speakers can distinguish Left and Right only categorically. Categorizing Left-Right is cognitively challenging and is hypothesized to delay learning to encode *Left-Right* spatial terms (Benton, 1959; Harris, 1972; Piaget, 1972; Sümer, 2015; see also Corballis & Beale, 1970). The way languages encodes these distinct spatial relations can vary across languages as well as in different modalities. These will be further elaborated on in the next section.

Figure 1

Objects in viewpoint-independent (a) and viewpoint-dependent (b&c) spatial configurations.



1.1.2. Linguistic Encoding of Locative Spatial Relations across Languages and Modalities: Speech, Sign, and Co-speech Gestures

1.1.2.1. Speech

Linguistic structures to encode space in speech have been found to exhibit a great deal of variation across different spoken languages. One way to express the spatial relation between the objects is through adpositions (i.e., prepositions and postpositions). Some languages, such as English, use spatial terms (e.g., *In-On-Under-Front-Behind-Left-Right* in English) in prepositional phrases. For instance, the spatial relations between the pen and the paper in Figure 1 can be expressed as “The pencil is *on* the paper”, “The pencil is to the *left* of the paper”, and “The pencil is in *front* of the paper”.

Some languages, such as Turkish, encode these spatial terms in morphologically complex postpositional phrases. For instance, in Turkish, a locative case marker (LOC) (*-de/da*) can be attached to spatial nouns to indicate the location of the Figure object with respect to the Ground object. Note that in these constructions, spatial nouns (e.g., *Sol* ‘Left’) are also inflected for the possessive marker (POSS) (e.g., *-un*) and Ground objects are inflected for the genitive marker (GEN) (e.g., *-ın*). See example 1 below for a detailed example from Turkish. Please note that the requirement of these markers (case, possessive, and genitive) makes Turkish morphologically complex and typologically different than many other languages such as English (see Johnston & Slobin, 1979 for the differences between English and Turkish on the levels of morphology, lexical diversity, and syntax).

(1)	Kağıd-ın	sol-un-da	kalem	var.
	Paper-GEN	left-POSS-LOC	pencil	there_is.
	GROUND	SPATIAL RELATION	FIGURE	

‘*The pencil is to the left of the paper.*’

Linguistic ways to express spatial relations in speech not only vary in terms of syntax and morphology but also vary in the way they exhibit specific semantic information about the spatial relation between the objects. This variation is seen both within a language and/or across different languages. For instance, in addition to specific spatial terms such as *Left-Right,* the spatial relation between the objects may be expressed by general spatial terms such as *Next to* in English or *Yan* ‘Side’ in Turkish. When we compare the information conveyed by specific spatial terms (i.e., *Left-Right*) to general spatial terms (i.e., *Next to* or *Side*), the latter may be ambiguous in conveying the exact spatial relation between the objects. Furthermore, in Turkish, a general locative case marker can be attached to the Ground object (rather than to the spatial noun). Such a construction indicates a containment and/support type of relationship between the Figure and the Ground items without specifying the exact spatial relationship and thus is ambiguous. Some languages might not even have specific relational terms to encode spatial relations between objects. For example, to convey spatial expressions Tzeltal employs a general locative marker (i.e., *ta*) as well as positionals (i.e., *waxal* and *lechel*). These positionals specify the size and shape of the Figure objects. For instance, *waxal* is used if the Figure object has a tall and round shape (such as a bottle) and *lechel* is used if the Figure object is flat (such as a plate) (see Brown, 1994). Unlike adpositions, positionals do not typically encode the nature of the spatial relation (e.g., containment, support), and the specific nature of the relation must be inferred from the semantics of the predicate that provides detailed information about the shape or orientation of the Figure object and/or from general world knowledge. Thus, spatial expressions in Tzeltal may not always convey the exact spatial configuration of the objects. See example 2 below that is obtained from Brown (2004).

(2) Kajal-0	waxal	ta	tz'ante'	ala	limete.
Mounted_on-ABS3	standing	PREP	beam	DIM	bottle.

‘The bottle is standing on the beam (above us).’

Finally, spoken languages also vary in the way they categorize spatial relations (Bowerman, 1989, 1996a, 1996b). For instance, in English, the preposition *On* can be used to express various spatial configurations such as “the key is *on* the table”, “the painting is *on* the wall”, and “the ring is *on* the finger”. By contrast, Dutch has different prepositions for these spatial configurations such as *Op*, *Aan*, *Om,* respectively. Thus, different languages may employ different linguistic categories to convey spatial information (e.g., Levinson, 2003; Levinson & Wilkins, 2006).

In spite of the variation they exhibit in encoding space, all spoken languages encode spatial relations in speech by transforming visual and three-dimensional relations into (mostly) categorical and linear linguistic structures that have an arbitrary relation to their meaning. By contrast, sign languages allow for visually motivated meaning mappings between the linguistic form and what it refers to in the real space. The nature and the type of linguistic structures present in sign languages are introduced in the next section.

1.1.2.2. Sign

Sign languages are natural languages that are expressed through visual-spatial modality by using hand, face, body movements, and space for linguistic encoding (Stokoe, 2005). Sign and spoken languages share basic linguistic properties on the levels of phonology, morphology, syntax, discourse, and pragmatics (e.g., Klima & Bellugi, 1979) and similar neural correlates concerning their linguistic processing (e.g., Emmorey, 2002; Emmorey & Özyürek, 2014). However, one of the aspects of sign languages that differs from speech is allowing for linguistic forms that bear a visually motivated link to the objects and spatial relations they express.

In sign languages the most frequent linguistic form for describing spatial relations between the objects is the use of morphologically complex forms, that is the so-called *classifier constructions* (e.g., Emmorey, 2002; Perniss et al., 2015a; Zwitserlood, 2012), as shown in Figures 2 and 3 below. In these constructions, in order to describe the spatial relation between the Figure and the Ground, signers first introduce the lexical signs for Figure and Ground objects, later they choose classifier handshapes to indicate the size and shape of these objects and they position these handshapes on the signing space in a way analogue to the real spatial configuration. The position and the location of the hands in signing space communicate information about the location of the objects (Emmorey, 2002; Perniss, 2007; Supalla, 1982; Zwitserlood, 2003) and the classifiers themselves are expressed by handshapes that *classify* entities by representing their salient characteristics, predominantly size and shape features (e.g., Emmorey, 2002; Janke & Marshall, 2017; Supalla, 1982; Zwitserlood, 2003; 2012). Morphological complexity in these forms is argued to be due to several factors such as the use of classifier handshapes (Bernardino, 2006; Brentari et al., 2013; Kantor, 1980; Morgan et al., 2008; Slobin et al., 2003; Supalla, 1982; Tang et al., 2007), the use of a location morpheme by placing hands on sign space (Schick, 1990; Zwitserlood, 2003), and representing the relative locations of Figure and Ground objects simultaneously in a classifier construction (Supalla, 1982; Slobin et al., 2003; Engberg-Pedersen, 2003; Tang et al., 2007; Morgan et al., 2008).

To illustrate, in order to describe the spatial relation between the cup and the toothbrush in Figure 2, signers first introduce the lexical signs for the cup (Figure 2a) and the toothbrush (Figure 2b), and later they choose classifier handshapes to indicate the size and shape of these two objects (Figure 2c). More specifically, signers choose a round handshape to represent the round nature of the cup and an elongated handshape (e.g., index finger) to represent the shape of the toothbrush. Later, they position their hands in the signing space in a way analogue to the real space. Thus, the representation of spatial relations between objects on the signing space maps onto the exact spatial relation between the objects in real space from a specific viewpoint (mainly from signer viewpoint). For instance, if the toothbrush was located on the left of the cup in the scene, then, the signer will position her index finger for the toothbrush at the left side of the handshape depicting the cup from her point of view and the other hand with a round shape to the right. Such constructions also show quite a bit of similarity across sign languages (see Figure 3).

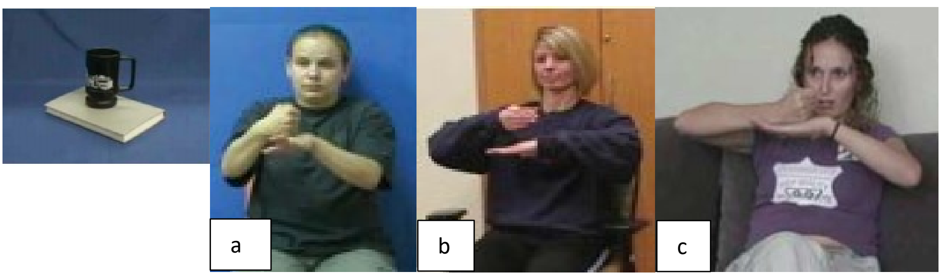
Figure 2

Example of a classifier construction by a TİD signer to encode the viewpoint-dependent spatial relation between the cup and the toothbrush.

RH:	-------------------	TOOTHBRUSH	CL(long)$_{Loc}$
LH:	CUP	CL(round)$_{Loc}$	---HOLD---

Figure 3

Examples of classifier constructions by signers of Croatian Sign Language (a), American Sign Language (b), and TİD (c) to encode the viewpoint-independent spatial relation between the mug and the book.



Notes. Examples were obtained from Arık (2009). Typically in all sign languages, before conveying the spatial relation between the objects through a classifier construction, signers introduce the lexical signs for the book and the mug. These are not included in the above examples.

Even though classifier constructions have been argued to be the most preferred linguistic form to encode spatial relations between the objects in sign languages (e.g., Perniss et al., 2015a; Talmy, 2003), signers can also use other linguistic forms to express spatial relation between the objects such as relational lexemes (akin to spatial nouns or prepositions in spoken languages; Arık, 2003; Sümer, 2015; Manhardt et al., 2020, 2021), tracing the objects' shape and locating them on the signing space (Perniss et al., 2015a), pointing to signing space to indicate the location of objects (Perniss et al., 2015a; Karadöller et al., 2021 as reported in **Chapter 3**), and lexical verb placements (Newport, 1988) (See **Chapter 2** and **Chapter 3** for more information and examples regarding these forms). Similar to classifier constructions, all of these linguistic forms encoding spatial relations have analogue mappings between the spatial relations in the real space and the linguistic form in the signing space. However, some of these forms lack iconic information about the size and shape of the objects such as in relational lexemes or pointing to space. Thus, these can be also considered as morphologically less complex in comparison to classifier constructions (Arık, 2003; Sümer, 2015). Nevertheless, all these different forms afford a higher potential for iconic representation of the spatial relation compared to what can be expressed by the arbitrary linguistic structures employed in speech.

1.1.2.3. Co-speech Gestures

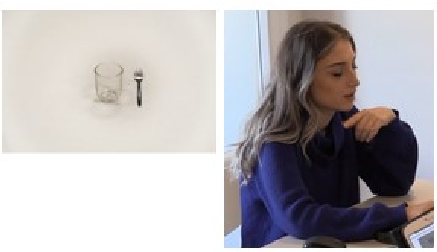
Visual-spatial modes of expressions allowing visually motivated encodings of space are not specific to sign languages. These types of expressions can also be found in spoken languages in the form of co-speech gestures. Co-speech gestures can be considered as universal communicative tools in the sense that all spoken languages are known to include gestures along with speech (Özyürek & Woll, 2019) – even though languages may vary in the frequency or types of gestures that their speakers utilize (see Azar et al., 2020; Kita & Özyürek, 2003). They can be also considered as “innate” communicative tools, as congenitally blind people have been observed to use gestures together with speech in different languages (Iverson & Goldin-Meadow, 1998; Mamus et al., under review; Özçalışkan et al., 2016).

Among many functions of co-speech gestures (see Church et al., 2017), they are used as expressive tools to convey information concerning the locations of objects in gesture space in iconic and analogue ways (e.g., McNeill, 1992, 2005; Sauter et al., 2012; Sekine, 2009). In these instances, co-speech gestures may provide information that is already conveyed in speech or may even convey information missing from speech (McNeill, 1992). For instance, when talking about locations in space, speakers sometimes encode space in linguistically ambiguous ways in speech by using deictic expressions such as *Here* and *There* while also using gestures to indicate specific locations in space (McNeill, 2005;

Peeters & Özyürek, 2016). In these instances, locational information can be conveyed through pointing gestures with the index finger or the palm that indicate the locations of objects on the gesture space. For instance, Figure 4 exemplifies the use of a directional pointing gesture indicating a location. In this example, although speech fails to give information regarding the exact spatial relation between the objects, the directional pointing gesture to the right gestural space indicates that the fork is on the right side of the cup. In addition to directional pointing gestures, speakers may use iconic hand placement gestures that indicate both the size and shape of the objects (in some ways similar to classifiers in sign languages but less conventional) and the objects' locations on the gesture space. In these configurations, handshapes represent the size and shape of the objects and placing these hands on the gesture space in an analogue manner represents their actual spatial configuration that is present on the real space (see more examples in the coding section of **Chapter 2**). A few other studies have also demonstrated that the use of gestures can accompany speech in children's spatial descriptions (Sauter et al., 2012; Sekine, 2009). For instance, spatial gestures have been found to co-occur with spatial information used in speech (e.g., use of Left-Right terms and mention of landmarks along the route) (Sekine, 2009). This previous research shows co-speech gestures are an integrated part of spoken languages as they convey visual-spatial information iconically with respect to the spatial relation expressed in speech.

Figure 4

An example from a Turkish speaker using a pointing gesture towards the right and conveying spatial information via both speech and co-speech gesture.



Bardağ-ın *yan-ın-da* *çatal* *var*

Cup-GEN *side-POSS-LOC* fork there-is

'There is a fork at the side of the cup'

Note. The underlined word denotes where gesture overlaps with speech.

1.1.3. Development of Spatial Language

Given the linguistic variation in encoding space in spoken and signed languages, it is interesting to see how children go about learning to encode spatial relations in their own language. Previous accounts on the development of spatial language propose that development of spatial language is the outcome of an interaction between the development of cognitive understanding of spatial relations, on the one hand, and the linguistic ways to express spatial relations, on the other. That is, language reflects and maps onto nonverbal conceptual development of space (e.g., Clark, 2004; Johnston, 1985, 1988) and at the same time children structure their semantic and conceptual understanding of space according to the language-specific semantic and syntactic ways to express spatial relations from very early on (e.g., Bowerman, 1996a, 1996b; Johnston & Slobin, 1979). Below, there is a review of this literature including what is known regarding the effect of cross-linguistic as well as cross-modal variation, focusing mostly on locative relations and Left-Right in particular.

1.1.3.1. Insights from Cross-Linguistic and Cross-Modal Variation

1.1.3.1.1. Cross-linguistic variation. For spoken languages, linguistic encoding of spatial terms has been found to follow a certain developmental order reflecting the cognitive complexity of the spatial relations reviewed above (1.1.1.). For instance, speaking children first acquire terms such as *In-On-Under* to refer to viewpoint-independent spatial relations between objects (e.g., Casasola, 2008; Casasola et al, 2003; Clark, 1973; Johnston & Slobin, 1979), followed by viewpoint-dependent relations such as Front-Behind (Durkin, 1980, 1981; Grigoroglou et al., 2019; Johnston & Slobin, 1979; Piaget & Inhelder, 1971). Linguistic encoding of viewpoint-dependent *Left-Right* relations, however, appears later (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015). This order has been attributed to the development of the nonverbal cognitive understanding of space (e.g., Clark, 2004; Johnston, 1985, 1988; Johnston & Slobin, 1979). Late acquisition of *Left-Right* is hypothesized to be related to the development of several conceptual steps: First, children seem to develop a conceptual understanding of their own Left and Right to map *Left-Right* spatial terms to refer to their body (Howard & Templeton, 1966). Next, they use these spatial terms to describe other people's Left and Right (Howard & Templeton, 1966; Piaget, 1972). Finally, it may take up to age 10 for speaking children to use these spatial terms to refer to the spatial relation between objects (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; see also Sümer, 2015 for Turkish).

Despite the similarities in learning to acquire spatial relations in a predictable order across languages, research has found differences in learning spatial language due to cross-linguistic variation in semantic structuring of spatial relations (e.g., Brown, 1994; Levinson, 1994, 1996; Talmy, 1985) and in morphological and syntactic ways to encode spatial relations (Allen et al., 2008; Johnston & Slobin, 1979). Namely, spatial relations have been found to be constructed in different ways across languages (see section 1.1.1.) and these differences may have consequences for learning to encode space. These possibilities have motivated the view that language-specific factors modulate the development of spatial language (Bowerman, 1996a, 1996b; Bowerman & Choi, 2001; Choi & Bowerman, 1991; Johnston & Slobin, 1979). In one of these studies, children have been found to tune into language-specific semantic categories and grouping principles very early on. For instance, series of cross-linguistic studies investigated the distinction between spatial relations denoting containment across English and Korean. In describing these types of spatial relations, English does not distinguish tight or loose fit between the Figure and the Ground. Thus, English speakers can use "*In*" for both cases. However, Korean speakers use verbs that distinguish between tight-fit "*kkita*" and loose-fit "*nehta*". Research has demonstrated evidence that English and Korean speaking children learn to use language-specific groupings early on (around 14-16 months of age). Secondly, research has also shown how variation in syntactic and morphological ways to encode spatial relations across languages modulate the order of learning to encode spatial relations. For instance, Johnston and Slobin (1979) found that even though the order of learning to encode certain groups of spatial relations are stable across languages (e.g., In-On-Under-Beside preceding Front-Behind-Between), the order of learning to encode specific spatial relations within these groups can vary across languages. These differences are attributed to the morpho-syntactic variation across languages. For instance, the use of adpositions in postpositional ways compared to prepositional ways has been shown to predict acquisition advantage in learning to encode spatial relations (Johnston & Slobin, 1979; Slobin, 1971). Moreover, adpositions (pre- and postpositions) that differ in the degree of morphological complexity such as using single morphemic forms have been argued to ease acquisition over multi morphemic forms (Johnston & Slobin, 1979). Thus, linguistic factors have the potential to guide the development of spatial language beyond the cognitive development of space.

1.1.3.1.2. Cross-modal variation. Despite the modality difference between sign and spoken languages, several studies have demonstrated similar language acquisition trajectories in many respects, such as in the emergence of vocal/manual babbling (Marenette & Mayberry, 2000), two-word utterances (Newport & Meier, 1985), and development of narrative discourse (Morgan, 2000; Sümer 2015). However, regarding spatial language development, signing and speaking children differ in the timing of learning to encode spatial relations due to the prevalence of visual-spatial modality allowing for iconic linguistic structures representing space more directly. Previous research has argued that morphological complexity of the sign language structures that encode space (i.e., classifier constructions) can delay their acquisition (e.g., Kantor, 1980; Newport & Meier, 1985; Schick, 1990; Supalla, 1982; Slobin et al., 2003 for American Sign Language; Engberg-Pedersen, 2003 for Danish Sign Language; Tang et al., 2007 for Hong Kong Sign Language). These findings come from the studies focusing on short event narrations, mainly with encoding motion events that have complex semantics (Talmy, 1985). However, recent research showed that when it comes to encoding locative spatial relations that are simpler than motion events, signing children have similar (Sümer, 2015; Sümer & Özyürek, 2020) or even earlier (Sümer, 2015; Sümer et al., 2014) acquisition trajectories compared to speaking children. For instance, signing and speaking children have similar acquisition trajectories when encoding spatial relations that do not require viewpoint (i.e., In-On-Under) (Sümer, 2015; Sümer & Özyürek, 2020). Furthermore, in the case of encoding relatively more complex spatial relations that require viewpoint (i.e., Left-Right), limited evidence suggested that signing children have an advantage and learn to encode these relations earlier than speaking children (Sümer, 2015; Sümer et al., 2014). This shows that having visually motivated forms of communication might be helping signing children to encode some of the spatial relations at the same time or earlier than speaking children. Thus, in general, previous research has shown that modality of language can modulate language development, thus questioning claims whether spatial language development merely reflects cognitive development of space (e.g., Bowerman, 1996a, 1996b; Johnston & Slobin, 1979).

Similar to sign language encodings, co-speech gestures can also convey spatial information due to their visually motivated affordances. However, there are very few studies investigating the role of gestures on the development of spatial language (e.g., Furman et al., 2006, 2010, 2014; Göksun et al., 2010; Özyürek et al., 2008; Sauter et al., 2012; Sekine, 2009). These studies showed that children's gestures can convey spatial information that is related to speech or even more information than what is expressed in speech. Based on this previous research, it is plausible that in situations where speech fails to give enough spatial information (i.e., not distinguishing Left from Right), gestures might help convey this information. This possibility, however, has not been investigated for expression of Left-Right relations that speaking children are known to be challenged and it is now well known whether speaking children spontaneously use such gestures in encoding such spatial relations in their speech or not. Thus, it is not known, if facilitating effects of visual-spatial encodings found for sign in learning to encode Left-Right relations (e.g., Sümer, 2015; Sümer et al., 2014) can also be extended to the use of gestures along with speech.

Thus, with regard to encoding Left-Right relations, previous research on cross-modal variation suggests that late development of learning to encode Left-Right in spoken languages may be simply due to a struggle to categorize symmetrically similar spatial layouts in the real space through the use of arbitrary form meaning mappings in speech (i.e., *Left-Right* terms) (e.g., Bowerman, 1996a). Visual-spatial forms that encode space iconically might perhaps make this mapping easier. If this is the case, encoding Left-Right relations could be another domain in which the language-specific encoding possibilities (e.g., as in tight-fit or loose-fit distinction) that children are exposed to in their language input might interact with cognitive development in shaping development of spatial language use.

1.1.3.2. The Effect of Late Sign Language Exposure

All of the studies reviewed above investigate the development of the expressions of spatial relations with speakers/signers who have been exposed to a spoken/sign language immediately following birth (Abarbanell & Li, 2021; Benton, 1959; Casasola, 2008; Casasola et al., 2003; Clark, 1973; Durkin, 1980, 1981; Grigoroglou et al., 2019; Johnston & Slobin, 1979; Piaget, 1972; Piaget & Inhelder, 1971; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014; Sümer & Özyürek, 2020). However, in the case of deaf children, there can be a huge variation concerning the age of exposure to a sign or spoken language. As mentioned at the beginning of this chapter, the majority of the deaf population is exposed to a sign language late, as they are born to hearing parents and may not have immediate access to a sign language (Mitchell & Karchmer, 2004).[2] Such a delayed exposure has consequences on their linguistic development in sign (see Lillo-Martin & Henner, 2021 for a review).

To this date, effects of late sign language exposure on the general linguistic abilities have been studied mostly by focusing on late signing adolescents who were exposed to a sign language during childhood or adolescence and late signing adults who were exposed to sign language during childhood (see Mayberry & Kluender, 2018 for a review). Studies comparing adolescent late signers to younger native signing children (groups matched in years of sign language exposure) found comparable performances between the groups in mean length of utterance (Ramirez et al., 2013; Berk & Lillo-Martin, 2012). Similarly, adolescent late signers have been found to go through stages similar to younger native signing children in the development of canonical word order (Cheng & Mayberry, 2019). Even though these studies showed similar developmental trajectories between late signers after late sign language exposure and younger native signers, none of them compared late signing children to their age-matched native signing counterparts directly. On the other hand, studies comparing late signing adults to their native signing counterparts showed that late exposure has long-lasting effects on grammaticality judgment of sentences in American Sign Language (Boudrelaut & Mayberry, 2006) and a decrease in recall performance of complex sentences in American Sign Language (Mayberry, 1993) as a function of the age of exposure to language.

[2] Although in many developed countries deaf children are provided with hearing aids and speech therapy, recent studies investigating the speech outcomes of children with cochlear implants show variable and unpredictable outcomes (see Hall et al., 2019 for a review) and thus cannot provide full early access to a spoken language.

When it comes to the spatial domain, there are only a handful of studies examining the effect of late sign language exposure on spatial language use. These studies have investigated the acquisition of motion event expressions either by late signing adults who were exposed to sign language during early (i.e., age 4-6) or late (i.e., after age 12) childhood (Newport, 1988, 1990) and adolescents (Morford, 2003) or homesigning children without a sign language exposure (Gentner et al., 2013). Studies on late signers have shown that early exposure to a sign language is crucial for mastering the use of morphologically complex verbs of motion (Morford, 2003; Newport, 1988, 1990). Studies with homesigner children have also shown that exposure to conventional language is crucial for the development of spatial expressions in language-like ways and that spatial expressions cannot emerge without any conventional sign language input (Gentner et al., 2013). For example, 5-year-old deaf children before being exposed to a sign language (i.e., homesigners) do not use any gestures that indicate spatial relations in ways encoded in sign languages (Gentner et al., 2013).

However, several issues regarding the role of late sign language exposure on development of spatial language remain unknown. First of all, it is possible that the detrimental effects found for late signing adolescents (Morford, 2003) and adults (Newport, 1988) are a reflection of the difficulty of the domain of motion events and that late exposure may not affect all aspects of spatial language development. For instance, nothing is known with regards to the effect of late sign language exposure on the development of locative spatial relations. Locative spatial relations are semantically (Talmy, 1985, 2003) and morphologically simpler than motion events (Sümer, 2015). Therefore, focusing on locative spatial relations as well as considering the cognitive complexity of different types of spatial relations (i.e., In-On-Under versus Left-Right) have the potential to bring new insights into whether late exposure influences the development of spatial language.

Secondly, to date, there is no information concerning how late signing children develop linguistic strategies for communicating about space shortly after being exposed to a sign language in comparison to their age-matched native signing peers. Without this knowledge, we cannot fully understand the role of late sign language exposure on the development of spatial language use and its relations to cognitive development. Namely, it will help uncover whether late signing children already have a developed nonverbal cognitive understanding of spatial relations even with the absence of language in the first six years of life and benefit from the visually motivated sign language forms to map onto these representations after exposure. If language merely maps onto nonverbal cognitive development after a brief exposure to a sign language, late signers might be on a par with their native signing peers in encoding spatial relations. However, if cognitive development of space is partially dependent on linguistic factors, late signers might lag behind their native signing peers.

1.1.4. Relation between Spatial Language and Spatial Memory

Going beyond how children go about learning to encode spatial relations considering the linguistic variation in modality and timing of language exposure, it is interesting to focus on whether these variations influence the relationship between spatial language use and its consequences for the subsequent memory of spatial relations. Previous research in spoken languages has shown knowledge and the use of spatial terms to be important predictors of children's spatial memory accuracy (Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Loewenstein & Gentner, 2005; Landau et al., 2011; Miller et al., 2016; Shusterman et al., 2011; Simms & Gentner, 2019). Evidence for this claim either comes from studies based on evidence for the positive correlation between children's use of specific spatial terms such as *Left-Right* (Hermer-Vasquez et al., 2001) and their spatial memory performance or from studies based on experimental evidence showing that providing children with spatial terms increased their accuracy in spatial memory tasks (Dessalegn & Landau, 2008; Lowenstein & Gentner, 2005).

1.1.4.1. Role of Language Modality

All of these above studies showing a relation between spatial language and spatial memory have investigated spoken languages with a specific focus on encoding spatial relations in speech. However, this approach under-represented spoken languages by excluding visually motivated information coming from gestures (except Abarbanell & Li, 2021 and Miller et al., 2016) and also neglected sign languages that express space through visually motivated ways. A few studies attempted to include the visual-spatial modality in their investigations (Abarbanell & Li, 2021; Miller et al., 2016). In Abarbanell and Li

(2021) and Miller et al. (2016), the benefit of gestures was investigated in isolation (in the absence of speech) and thus only provided comparisons across speech and gesture. These studies showed conflicting evidence for the use of gestures in insolation during a memory task by reporting either a better (Abarbanell & Li, 2021) or worse (Miller et al., 2016) memory accuracy compared to speech alone. Thus, no study so far compared speech to speech-gesture combinations. Moreover, no study so far compared sign to speech and speech-gesture combinations. Focusing on speech-gesture combinations is especially important when comparing spoken languages to sign languages (Özyürek & Woll, 2019).

A few studies provided evidence that performing actions during encoding promotes better memory representations than verbal encoding only, possibly due to the involvement of the motor system leading to richer and/or stronger memory representations (see Cohen, 1989 and Nilsson, 2000 for reviews). Execution of signs and co-speech gestures may recruit hand movements that resemble the movements executed in tasks that are used in performing actions. Thus, linguistic encoding through sign or co-speech gestures may be comparable to performing actions. Previous work provided evidence –albeit outside of the spatial domain– that encoding through signing promotes better memory accuracy compared to verbal encoding only and this effect has been found to be as strong as performing actions (von Essen & Nilsson, 2003; Zimmer & Engelkamp, 2003).

Therefore, previous work hasn't investigated whether spatial encoding via sign is a more powerful tool compared to speech in enhancing spatial memory. In addition, it is not known if co-speech gestures are taken into account together with speech in comparison to sign such effects will still be observed. Overall, based on previous research (von Essen & Nilsson, 2003; Zimmer & Engelkamp, 2003) it is plausible to expect encoding with visual-spatial forms to predict better memory compared to encoding with speech.

1.1.4.2. Role of Late Language Exposure

Even though no study so far investigated whether late language exposure influences memory for spatial relations, some have looked into cases of deaf children with no language exposure. Studies investigating a single deaf adolescent (Hyde et al., 2011) or a group of deaf children who have not been exposed to a conventional language (Gentner et al., 2013) show first of all that encoding spatial relations is not possible in the absence of conventional spatial language exposure. Secondly, this research has also shown that having a linguistic system for conveying spatial relations is essential to perform tasks that require memory for spatial locations (Gentner et al., 2013; see also Gentner, 2016 for a review). Further research is required to understand how deaf children, after exposure to a sign language, perform in spatial memory tasks in comparison to their native signing counterparts. Moreover, it is important to uncover whether differences in spatial language use of morphologically complex versus simpler linguistic forms (e.g., classifier construction versus pointing) due to late sign language exposure predict differences in spatial memory.

1.2. The Present Thesis

The present thesis intends to fill the gaps present in the above-reviewed literature on the development of spatial language and its relation to cognition. It focuses on the variation in language modality and variation in the timing of language exposure as possible factors influencing this relationship. To do so, it raises three overarching questions that are explored in four experimental studies presented in **Chapters 2 to 5**. The subsequent section contains the general research questions pertaining to the main investigations of this thesis, information concerning the participant groups and methodology, followed by the main predictions, and the general overview of the remaining chapters.

1.2.1. Main Research Questions

(RQ1) Does the variation in language modality as in speech, sign and co-speech gestures modulate how children use spatial language? (**Chapter 2**)

(RQ2) Does the variation in the timing of language exposure modulate using spatial language, as in deaf late and native signers? (**Chapter 3**)

(RQ3) Do modality of language use (investigated in RQ1) and the timing of language exposure (investigated in RQ2) influence subsequent memory for spatial relations?

- (RQ3a) Does the modality of linguistic encoding predict subsequent memory for spatial relations? (**Chapter 4**)

(RQ3b) Does late sign language exposure, as well as the differences in spatial language use due to late sign language exposure, predict memory for spatial relations? (**Chapter 5**)

The domain of locative spatial relations is chosen as the empirical focus of experimental studies presented in **Chapters 2 to 5**, especially Left-Right for two reasons: First, locative spatial relations is a domain in which most of the previous work has been carried out including work on Turkish and TİD (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). Therefore, this focus allows building on the previous work more directly. Secondly, encoding Left-Right spatial relations is known to be cognitively challenging as explained in the literature review above and allows to better investigate the interplay between linguistic and cognitive development.

The rationale for choosing TİD and Turkish in the current thesis is the following. First of all, these languages have been chosen as previous work established linguistic encoding patterns of child and adult deaf native signers of TİD and child and adult hearing monolingual speakers of Turkish (Sümer, 2015) and allow us to build on these patterns directly. Secondly, Turkish has been chosen because it employs morphologically complex structures for encoding spatial relations in ways that are comparable to classifier constructions present in sign languages. Moreover, although not directly studied for the domain of space, Turkish has been found to be a high gesture culture in general (Azar et al., 2020). Thus, Turkish children and adults might make use of gestures in their descriptions of spatial relations.

Differences in spatial language use due to variation in language modality (RQ1) and timing of language exposure (RQ2) are investigated by asking participants to describe pictures of objects in various spatial configurations. Relation between spatial language use and spatial memory accuracy (RQ3) is explored by asking participants to remember the pictures they had described in a surprise recognition memory task. Based on the description task, results concerning the variation in language modality are reported in **Chapters 2 and 4** and results concerning variation in the timing of language exposure are reported in **Chapters 3 and 5**. Results of the memory task in relation to the variation in language modality are reported in **Chapter 4** and in relation to the variation in the timing of language exposure are reported in **Chapter 5**.

1.2.2. Methodology

1.2.2.1. Participants

Data were collected from congenitally and profoundly deaf native and late signers of TİD and hearing monolingual speakers of Turkish. There were two main age groups: children and adults. See Table 1 below for the distribution of participant groups across each chapter. For children, we specifically focused on 8 years of age for two reasons. First of all, we wanted to ensure that children have a nonverbal cognitive readiness to learn to encode Left-Right spatial relations that were found to be acquired no earlier than age 8 by speaking children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). Second, we wanted late signing children to have at least 2 years of exposure to acquire basic structures of the language. All children (late signing, native signing, and speaking) started school at the age of 6. For late signing deaf children, this was the first time they were exposed to sign language through interacting with other deaf children at the school (as formal instruction is not given in TİD in the deaf schools of Turkey). Late and native signing children were recruited from the same schools and thus they were classmates. Consequently, at the time of testing, late signing children had 2 years of exposure to a sign language in the school environment. All adults (late signing, native signing, and speaking) started school at the age of 6 and the majority of signing adults attended the same schools as the deaf children.

All participants reported in this thesis were born and raised in Turkey. The sample size in each group is based on convenience for **Chapters 2, 4, and 5**. Working with special populations poses certain challenges in reaching participants. Here, we report data from native signers who had been exposed to a sign language from birth by their signing deaf parents. This group represents 10% of the deaf population in the world (Mitchell & Karchmer, 2004) and also in Turkey (İlkbaşaran, 2015). Hence, the number of participants in other groups (child and adult late signers and hearing speakers) reported in this study was determined based on the total number of native signing children attending the deaf schools in İstanbul that we could collect data from.

Box 1.1. Historical Background of the Turkish Sign Language

A drawing of a Mute.
Courtesy of Prof. Dr. Ekrem Buğra Ekinci (2017).

Even though the historical background of TİD is very limited, it has been argued to be the continuation of the Harem Sign Language (Seraglio Sign Language) (Ekinci, 2017). Yet, there is no clear documentation that shows similarities between TİD and Harem Sign Language. Dating back to the 16th century, deaf individuals have been recruited in the Ottoman Palace as servants and in the Ottoman Court System as executioners and guards (Miles, 2000). The idea behind this choice originates from the concern for secrecy within the harem (the Imperial household) and with respect to the administrative decisions and executions. Such a preference put deaf individuals in a strategic position and helped development and spread of the sign language (see Kemaloğlu & Kemaloğlu, 2012 and Dikici, 2006 for a

Despite the acknowledgment of sign language in the Ottoman Palace and the Court, the first schools for the deaf were established at the beginning of the 20th century. These schools were first established in larger cities such as İstanbul to cover only primary education (Deringil, 2002; Kemaloğlu & Kemaloğlu, 2012). TİD has been shared and spread among the deaf individuals in Turkey with the help of these schools and Deaf associations throughout the years.

In recent years, schools for the deaf increased in numbers and educational levels. Currently, several schools are employing primary, secondary, and high school level education for deaf individuals (İlkbaşaran, 2015).

We collected data from all students from these schools who matched our criteria (e.g., age, absence of comorbid health issues such as problems with vision, or diagnosis with intellectual problems such as intellectual disability). Finally, to our knowledge, the current sample incorporates the largest number of native and late signers in comparison to previous studies conducted so far. Moreover, we could not balance the gender diversity within the adult group as we had to collect data from almost all deaf adults living in İstanbul falling under our criteria.

Table 1

Distribution of participant groups across the empirical chapters.

	Native Signers		**Late Signers**		**Speakers**	
Chapter 2	*Children* N = 21 Mean Age = 8;5	*Adults* N = 26 Mean Age = 29;10			*Children* N = 24 Mean Age = 8;6	*Adults* N = 23 Mean Age = 35;9
Chapter 3	*Children* N = 11 Mean Age = 8;5	*Adults* N = 10 Mean Age = 31;4	*Children* N = 9 Mean Age = 8;5	*Adults* N = 12 Mean Age = 38;2		
Chapter 4	*Children* N = 21 Mean Age = 8;5	*Adults* N = 26 Mean Age = 29;10			*Children* N = 24 Mean Age = 8;6	*Adults* N = 23 Mean Age = 35;9
Chapter 5	*Children* N = 21 Mean Age = 8;5	*Adults* N = 26 Mean Age = 29;10	*Children* N = 23 Mean Age = 8;6	*Adults* N = 23 Mean Age = 36		

Notes. Participants indicated in light yellow and light blue were taken from Sümer (2015). Participants indicated in darker colors were collected for the purposes of the present thesis. Thus, native signers recruited in **Chapters 2, 4, and 5** (dark yellow) came from a different set of native signers presented in **Chapter 3** (light yellow). Similarly, late signers recruited in **Chapter 5** (dark blue) also came from a different set of late signers presented in **Chapter 3** (light blue). Speakers recruited in **Chapters 2 and 4** were the same participants.

Based on the language background questionnaire collected from child and adult deaf signers, [3] the average age that participants were exposed to spoken Turkish first time was 7,66 (Age Range = 2 – 22). 18% of the participants were reported to be exposed first time to spoken Turkish at home, 58% at school, 21% at both home and school, and the remaining 3% reported themselves to be exposed to Turkish in any other place. Moreover, participants' average self-rated Turkish fluency scores out of 6 were the following: speaking fluency was

[3] This information was obtained from adults themselves. For children, we obtained this information either from their parents or their primary school teachers.

3.20, comprehension fluency was 3.34, writing fluency was 3.44, and reading fluency was 3.49. Thus, on the basis of these reports, we consider their Turkish proficiency to be medium. Please see appendix for the use of hearing devices for deaf participants as well as information over handedness for all participants.

Box 1.2. Linguistic Background of TİD Signers and Educational System of the Schools for the Deaf in Turkey

Deaf children with deaf parents (i.e., native signers) learn TİD from their caregivers. Unlike in countries that offer early interventions, in Turkey, deaf children do not typically get speech therapy or TİD exposure in a conventional setting (e.g., school). Deaf children with hearing parents (i.e., late signers) typically learn TİD after they attend the school for the deaf. In these schools, TİD is not part of the main curriculum as these schools employ *oral education* in written and spoken Turkish. Thus, deaf children are exposed to written Turkish in the classroom environment and are exposed to TİD during recess while interacting with their peers. More information concerning the Turkish context can be obtained from İlkbaşaran (2015).

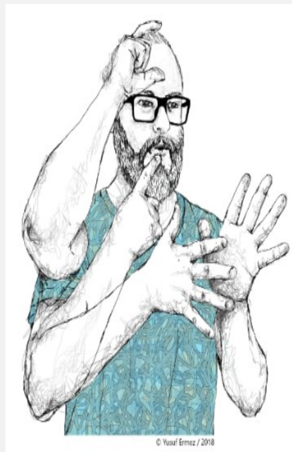


Illustration of the signs for TİD in TİD. Created by Yusuf Ermez.

1.2.2.2. Materials

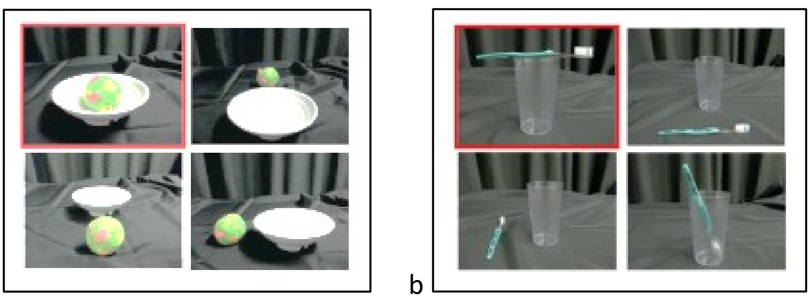
Materials consisted of pictures of objects in various spatial configurations to elicit spatial language descriptions in the description task as well as to assess subsequent recognition memory performance in the recognition memory task. Please note that the pictures used in **Chapter 3** were different than those of **Chapters 2, 4, and 5** (See Figures 5 and 6 for a comparison). The rationale for the difference in **Chapter 3** resulted from our motivation to build on a prior work that reports picture descriptions for viewpoint-independent and viewpoint-dependent spatial relations by native signing children and adults (i.e., Sümer, 2015). Therefore, in **Chapter 3**, we collected data from a different group of age-matched late signing children and adults using the same stimuli materials and methodology used in Sümer (2015) for a direct comparison. Note that, the stimuli materials used in **Chapters 2, 4, and 5** will be reviewed more in detail in the current chapter. Please consult **Chapter 3** for details on different stimuli materials.

The stimuli of the description task reported in **Chapters 2, 4, and 5** consisted of 84 displays with 4 pictures showing the same two objects (Figure and Ground) in various spatial configurations (i.e., Left-Right-Front-Behind-In-On). Ground objects (e.g., jar) were always in the center of the pictures and lack intrinsic features such as front and back. Figure objects (e.g., lemon) changed their location with respect to the Ground Objects. As a result, 4 pictures in one display differed only in terms of the position of the Figure object. This manipulation aimed to foreground spatial relations between the objects rather than the objects themselves and allowed us to ensure that participants mentioned the spatial relation between the objects as a distinguishing feature of the target picture in their descriptions. Each display had one target picture indicated by an arrow (Figure 6a). For the purposes of the research reported in **Chapters 2, 4, and 5,** we only focused on target pictures that have objects in Left-Right spatial relations to each other. Please see **Chapters 2, 4, and 5** for more details.

Stimuli of the memory task reported in **Chapters 4 and 5** consisted of a sample of the same displays (n = 54) without the arrow. Display order and the arrangement of the 4 pictures in one display were randomized for the recognition memory task (Figure 6b). Please see **Chapters 4 and 5** for more details.

Figure 5

*Example displays of the description task used in **Chapter 3**.*

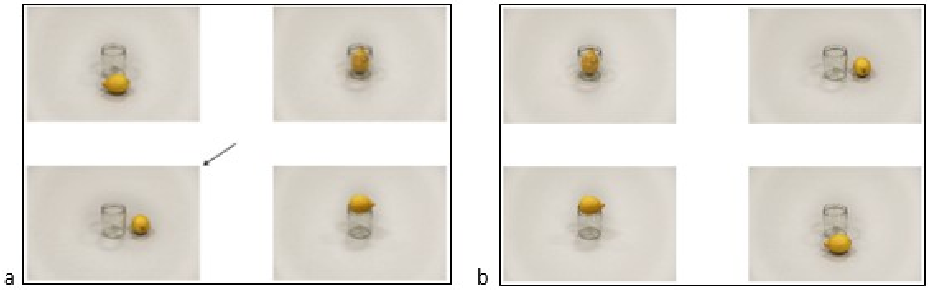


a b

Notes. Examples of displays were adapted from Jennie Pyers (Wellesley College). Red rectangle indicated the target item to be described to an addressee.

Figure 6

Example displays of the description (a) and memory tasks (b) used in ***Chapters 2, 4, and 5****.*



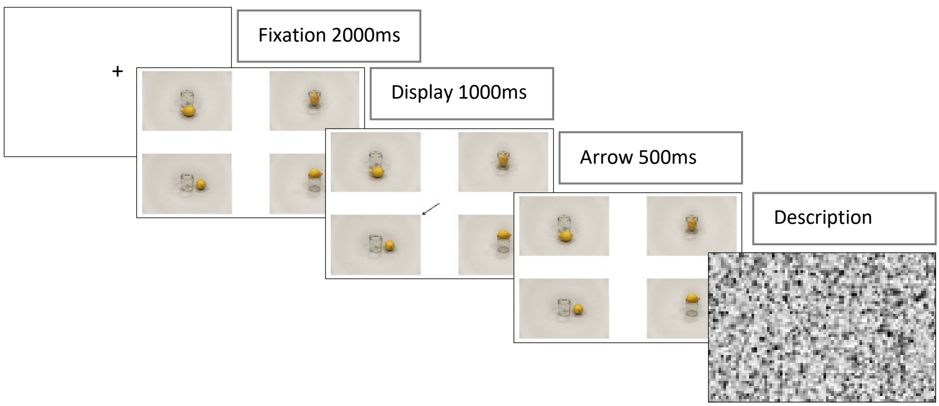
1.2.2.3. Procedure

The procedure used in **Chapters 2, 4, and 5** will be reviewed in detail in the current chapter. Please consult **Chapter 3** for slight differences in methodology compared to other empirical chapters. Each participant was tested in a quiet room. Participation was voluntary and at the end of the study all children received a gender-neutral color pencil kit and adult participants received monetary compensation for their participation. All instructions were given orally in Turkish to speaking children and adults by a Turkish speaking adult and in TİD to signing children and adults by a deaf TİD signing adult. No written instructions were used to avoid misunderstandings by children and also by TİD signers as written Turkish is not their native language. The language status of the addressees was also matched with that of the participants. Addressees were confederates and pretended to find the specific picture of the display in the tablet based on signer's/speaker's description. The rationale for having a confederate addressee was to ensure consistency across sessions especially for children considering the previous reports on children's tendencies to be under-informative in the presence of an inattentive addressee or in the absence of an addressee (Bahtiyar & Küntay, 2009; Girbau, 2001; Grigoroglou & Papafragou, 2019).

In the description task, each trial started with a fixation cross (2000ms), followed by a 4 picture display (1000ms). Next, an arrow was presented for 500ms targeting one of the pictures in the display and disappeared. Next, the display with 4 pictures remained on the screen for an additional 2000ms until the visual white noise screen appeared. Participants described the target picture to an addressee during the visual white noise. This was done to avoid children's tendency to point towards to screen during description. After the description, the addressee chose the picture that the participant described on her tablet. Participants moved to the next trial by pressing the ENTER key. This task was video recorded from side-top and front angles for later coding for the sign, speech, and gesture. See Manhardt et al. (2020) for a similar procedure. Please see Figure 7 for the timeline of a description task and Figure 8 for the experimental setup and the camera angles for videotaping.

Figure 7

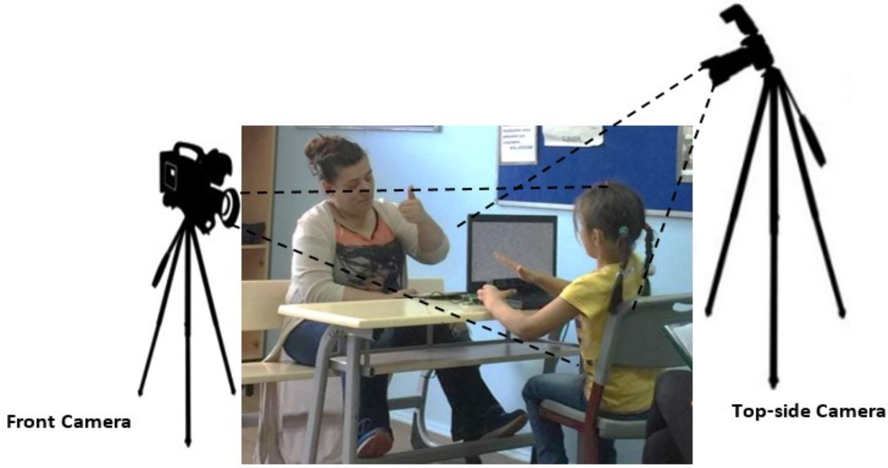
*Timeline of a trial in the description task (**Chapters 2, 4, and 5**).*



Following the description task, participants completed a Flanker Task as a distractor before the surprise recognition memory task. Adult participants received the original Flanker Task (Eriksen & Eriksen, 1974) (duration was approximately 15mins) and child participants received the child-friendly version with fish (Rueda et al., 2004) (duration approximately 5mins). In the surprise recognition memory task (reported in **Chapters 4 and 5**), participants were given the same displays and asked to click on the picture that they had previously described by using the mouse. Asking participants to remember the same picture that they have described previously in the description task allows us to have a one-to-one correspondence between the spatial language use and spatial memory. Moreover, the rationale for having this task as a surprise was to eliminate possible influences on the production performance.

Figure 8

Example of the experimental setup.

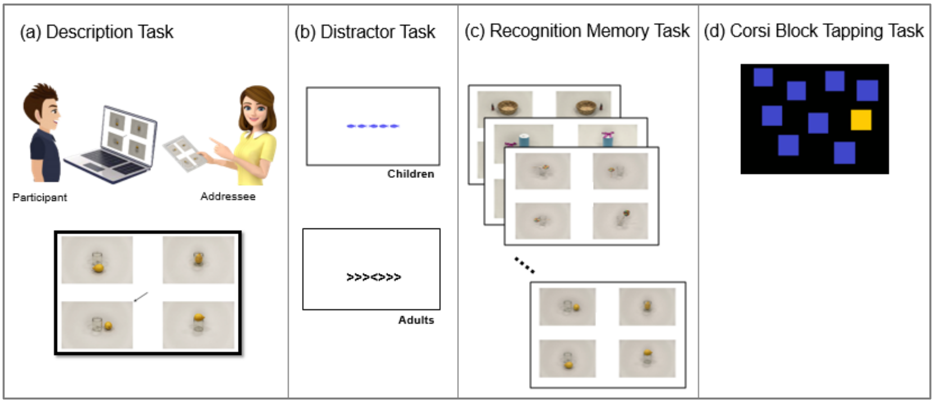


Notes. The child participant is describing the target picture during visual white noise to the addressee sitting across the table. Addressee is looking at the tablet on her hand to pick up the described picture. There were two cameras that were not present in this picture. Cameras were placed from the front and top-side angles filming the participant only. Dashed lines show filming angles.

Lastly, after the memory task was completed, participants received the computerized version of the Corsi Block Tapping Task (Corsi, 1972) in forward order. The results of this task allow for making comparisons across the language groups in terms of visual-spatial working memory span in **Chapters 2, 4, and 5** (see Marshall et al., 2015 for similarities and differences between speaking, native, and late signing children in visual-spatial working memory span; see Emmorey, 2002 for adult comparisons). Please see Figure 9 for the overall flow of the procedure featuring Description Task, Distractor Task, Recognition Memory Task, and the Corsi Block Tapping Task.

Figure 9

Flow of the procedure featuring (a) Description task; (b) Distractor Task; (c) Recognition Memory Task; (d) Corsi block Tapping Task.



1.2.2.4. Annotation and Coding

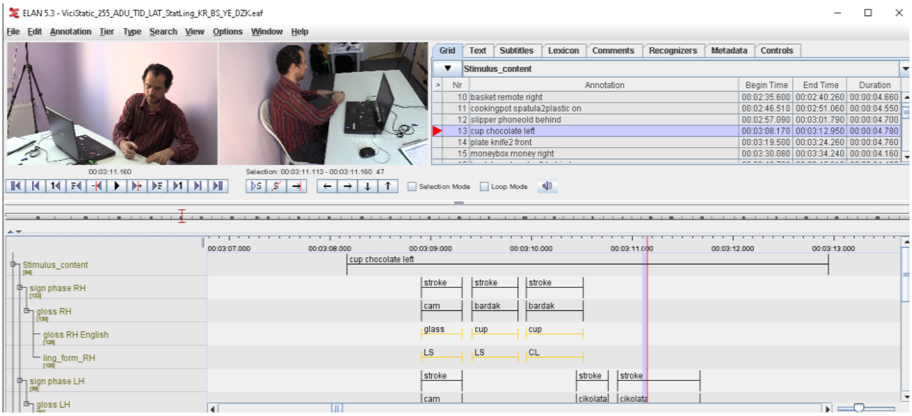
All descriptions produced in the description task were annotated for Target Pictures in Left-Right spatial configurations for coding of sign, speech, and co-speech gestures. All annotation and coding were done in ELAN (Version 4.9.3.), a free annotation tool (http://tla.mpi.nl/tools/tla-tools/elan/) for multimedia resources developed by the Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Wittenburg et al., 2006). See Figure 10 for screenshots of ELAN windows for annotation and coding of sign (a) and spoken (b) language data.

Sign data were annotated by a hearing L2 signer of TİD and coded by another hearing L2 signer of TİD. All annotation and coding were checked by a deaf native signer of TİD. Only the annotations and coding approved by this deaf native signer were included. Speech and gesture data were coded by a native speaker of Turkish. For gesture, 20% of the data were coded by another native speaker of Turkish for reliability check (see **Chapter 2** for further details). Please consult each chapter for the specifics of coding. Data is archived in The Language Archive, Nijmegen, The Netherlands and available on request to other researchers.

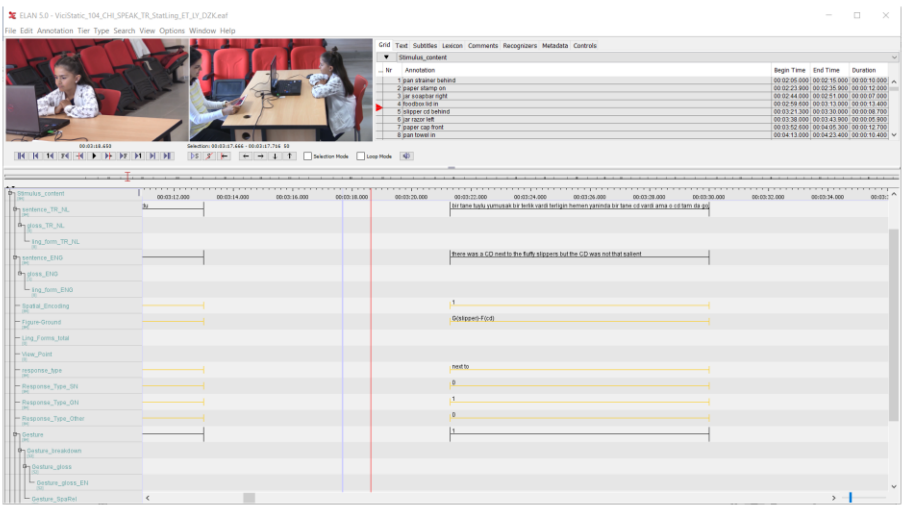
Figure 10

Screen shot of ELAN window for sign (a) and spoken (b) language coding.

a



b



1.2.3. Overview of the Chapters and Predictions

In an attempt to answer the main research questions stated above, this thesis incorporates four empirical chapters (**Chapter 2, Chapter 3, Chapter 4, and Chapter 5**) which are based on manuscripts that have been published as a peer-reviewed journal article (**Chapter 3**) or appeared as conference proceeding papers (**Chapter 3, Chapter 4**) or are currently accepted for publication (**Chapter 5**) or under review (**Chapter 2**) in peer-reviewed journals. Each chapter can be viewed as a self-contained paper including its Abstract, Introduction, Methodology, Results, and Discussion sections. There may be some overlap between the literature reviews and methodology across chapters. Even though for **Chapters 2, 4, and 5** overlapping data sets are used, there are differences in how the coding was done. These differences are explained in relevant chapters.

The first two chapters focus on the development of spatial language use from the perspective of modality differences (**Chapter 2**) and late sign language exposure (**Chapter 3**), respectively. Next, the remaining chapters further investigate whether spatial memory can be modulated by the variation in language modality (**Chapter 4**) and variation in the timing of sign language exposure (**Chapter 5**). Please see Figure 11 for the diagrammatical distribution of participant groups and experimental tasks across the chapters. In the remainder of this chapter, there is a brief description of each chapter concerning the main predictions.

Chapter 2 investigates whether the variation in language modality as in speech, sign, and co-speech gestures modulates how children use spatial language (RQ1) considering the informativeness of the expressions regarding Left-Right relations by comparing native signers and speakers. In this chapter, informativeness is defined as how the participants' descriptions distinguish the spatial relation between the objects in the target picture among other spatial relations (i.e., remaining pictures in the display other than the target picture) (see Grigoroglou & Papafragou, 2019a for a similar approach in the domain of events). The main goal of this chapter was to understand whether the challenge of learning to encode Left-Right relations is present regardless of the modality of expression or if this challenge is modulated by using iconic ways to encode space (i.e., sign and co-speech gestures) compared to using arbitrary forms as in speech. While making comparisons across modalities (i.e., sign versus speech), signers, in general, and signing children in particular, were expected to be more informative than speakers due to the affordances of visually motivated representations of space facilitating informativeness. However, when co-speech gestures are considered on top of speech, the use of co-speech gestures was expected to increase the informativeness of expressions, and thus speakers were expected to be equally informative to signers.

Fiure 11

Diagrammatical distribution of participant groups and tasks across the chapters.

	Native Signers	Late Signers	Speakers
Chapter 2			
Chapter 3			
Chapter 4			
Chapter 5			

Notes. Spatial language use data are indicated for sign language with *hands* icon only, spoken language data with *speech bubble* for speech, and *speech bubble with hands icon* for speech-gesture combinations. Different colors are used to indicate language use data of different groups (i.e., yellow for native signers, blue for late signers, and orange for speakers). Spatial memory data are indicated by the head icon with gear wheels.

It is also possible to expect signers to be more informative than speakers even when their co-speech gestures are taken into account, especially for children considering a developmental challenge in encoding Left-Right by speaking children. This outcome would indicate that acquiring visually motivated linguistic forms as part of the conventional linguistic system as in sign languages (Brentari, 2010; Emmorey, 2002; Klima & Bellugi, 1979; Stokoe, 1960) might facilitate encoding Left-Right relations compared to co-speech gestures that are not learned as part of the linguistic system of spoken languages and rather form a composite system together with speech (Kendon, 2004; McNeill, 1992, 2005; see Özyurek & Woll, 2019 and Perniss et al., 2015b for a discussion). If such effects of modality are found, this would indicate that visually motivated forms modulate semantic and conceptual understanding of space (e.g., Bowerman, 1996a, 1996b). However, learning to encode Left-Right relations in speech, sign, or co-speech gestures might still be challenging for children and even at 8 years of age children may not encode Left-Right in adult-like frequencies. Such a finding has the potential to add evidence to the literature claiming that Left-Right is a difficult domain for speaking children (Abarbanell & Li, 2021; Clark, 1973; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014) and would indicate a universal cognitive challenge in encoding Left-Right regardless of language modality (e.g., Clark, 2004; Johnston, 1985, 1988).

Chapter 3 focuses on the variation in the timing of language exposure and asks if this variation modulates using spatial language (RQ2). To do so, it compares late signing children (after two years of exposure to a sign language) and adults to their age-matched native signing counterparts to see if late language exposure influences spatial language development. Here, linguistic encoding of two types of spatial relations is compared that have been found to differ in cognitive complexity: viewpoint-independent relations (In-On-Under), which are simpler and acquired earlier, and viewpoint-dependent relations (Left-Right), which are complex and acquired later. It is investigated whether linguistic forms to encode space can develop in the case of late exposure to a sign language. If cognitive development is partially independent of language, late signers even after a short exposure to language (i.e., 2 years) could map linguistic forms onto spatial concepts and be on par with their age-matched native signing peers. However, if linguistic factors play a role in spatial language development we might expect delays in late signers compared to native signers and we also expect morphological complexity of spatial forms to play a role here as well. Considering the two types of spatial relations we entertain three possibilities: First, it is possible to see the order of conceptual development of space playing a driving role in the development of spatial language. That is, viewpoint-dependent relations might be delayed compared to viewpoint-independent relations as they have been found to be learned later by speaking children (e.g., Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Sümer, 2015). Second, if linguistic factors play a shaping role in development of spatial concepts, then, late signers might lag behind their native signing peers.

Here, the morphological complexity of the different linguistic forms can also play a role in late sign language exposure (see Newport, 1988, 1990). That is, late signers might use morphologically complex forms (i.e., classifier constructions) less frequently compared to morphologically simpler forms (e.g., pointing). Third, it was possible to observe an interaction between cognitive and linguistic factors playing a driving role in shaping spatial language development. That is, late exposure might hinder the acquisition of morphologically complex linguistic structures only when expressing cognitively complex spatial relations (i.e., viewpoint-dependent ones but not viewpoint-independent ones).

Chapter 4 aims to find out whether signing versus speaking modulates spatial memory (RQ3a). Specifically, this chapter investigates whether or not linguistically encoding a spatial relation between the objects in Left-Right spatial relations predicts subsequent recognition memory accuracy for these relations for native signers versus speakers. Furthermore, it investigates whether modality of encoding through "*speech alone versus speech-plus-gesture*", "*speech alone versus sign"* or "*sign versus speech-plus-gesture"* predict spatial memory accuracy differentially. Based on the previous accounts showing that encoding through language, in general, promotes better spatial representations (e.g., Dessalegn & Landau, 2008; Gentner, 2016), it was predicted that descriptions that encode spatial relation would predict better memory than descriptions that do not encode spatial relation both in sign and speech –extending previous research to sign language encodings. Moreover, it was further predicted that encoding spatial relations in sign and speech-plus-gesture would predict better memory accuracy than encoding in speech due to iconicity of the linguistic encoding facilitating learning to encode Left-Right (e.g., Sümer, 2015) and to the possible activation of the motor system (Cohen, 1989; Nilsson, 2000) having potentials to create stronger and/or richer memory representations. Finally, when sign is compared to speech-plus-gesture, there were two possibilities: First, encoding the spatial relation in sign and speech-plus-gesture might not generate significant differences in memory accuracy. This might be because taking gestures into account better represents spoken languages by incorporating iconic forms and activation of the motor system. Alternatively, signing children might outperform speaking children even when speaking children's gestures are taken into account due to the conventional and obligatory ways to encode space in sign promoting better representations but not in co-speech gestures. In either way, these outcomes shed new light on the interplay between iconicity in the spatial expressions influencing the relation between spatial language and subsequent memory.

Finally, **Chapter 5** aims to find out whether the timing of sign language exposure and/or type of linguistic encoding due to late exposure modulates spatial memory (RQ3b). Specifically, it investigates whether or not linguistically encoding a spatial relation between the objects in Left-Right spatial relations predicts subsequent recognition memory accuracy for these relations for native versus late signers. Furthermore, it investigates whether or not late sign language exposure, as well as the differences in spatial language use due to late sign language exposure, predict spatial memory accuracy. There were two main goals of this chapter: The first goal was to replicate previous findings from **Chapter 3** concerning the effect of late sign language exposure on the frequency and type of spatial language use of Left-Right spatial relations. To do so, **Chapter 5** zoomed only into viewpoint-dependent spatial relations (i.e., Left-Right) by incorporating more stimuli items that were balanced (identical to stimuli materials used in **Chapters 2 and 4**) and a higher number of late and native signers who were matched in terms of schooling experience and non-linguistic spatial memory performance. The second goal was to investigate whether the effects of late sign language exposure extend beyond the domain of spatial language use and predict subsequent spatial memory accuracy. Similar to what is predicted in **Chapter 4** and based on the previous accounts showing that encoding through language promotes better spatial representations (e.g., Dessalegn & Landau, 2008; Gentner, 2016), it was expected that descriptions that encode spatial relation predict better memory than descriptions that do not encode spatial relation regardless of the timing of sign language exposure. Alternatively, late signers might lag behind their native signing counterparts in spatial memory due to having less experience with conventional language. Finally, it was predicted that linguistic differences obtained due to late exposure such as the use of different types of linguistic forms (linguistic forms with more iconic features such as encoding size and shape of the objects in addition to encoding spatial relation between the objects or only encoding the spatial relation between the objects) may predict spatial memory differently. These would indicate not only encoding a spatial relation but the way of encoding it might predict subsequent memory.

Chapter 6 provides a summary of findings presented in **Chapter 2**, **Chapter 3**, **Chapter 4**, and **Chapter 5** and discusses theoretical implications of these findings concerning the complex interplay between the linguistic and cognitive development of spatial relations and the robustness of the correspondence between spatial language use and spatial memory accuracy. Finally, this chapter ends by highlighting the methodological contributions of the current thesis for the investigation of spatial language use and its relations to spatial memory accuracy, future directions for exploring the development of spatial language, and societal implications.

Chapter 2: Signing Children's Spatial Expressions are More Informative than Speaking Children's Speech and Gestures Combined

This chapter is based on:

Karadöller, D. Z., Sümer, B., Ünal, E., & Özyürek, A. (Under Review). Sign advantage for children: Signing children's spatial expressions are more informative than speaking children's speech and gestures combined.

Abstract
Previous work with speaking children has shown that Left-Right is a challenging domain for linguistic encoding and is acquired late in development. Yet, this challenge has not been found for signing children who express Left-Right relations in adult-like ways earlier than their speaking peers possibly due to iconicity of sign language expressions of spatial relations. We investigate whether there is still a modality advantage in expressing Left-Right relations for signers compared to speakers when speaking children's co-speech gestures are considered together with their speech. To test this possibility, 8-year-old child and adult hearing monolingual Turkish speakers and deaf signers of Turkish Sign Language (*Türk İşaret Dili* [TİD]) described pictures of objects in various spatial relations. Descriptions were coded for informativeness in speech, sign, and speech-gesture combinations. Informativeness was defined in terms of whether the description distinguishes the spatial relation in the target picture uniquely from the other spatial relations in the pictures in the same display. Results showed that the use of co-speech gestures indeed increased the informativeness of expressions in speaking children compared to speech. However, signing children were more informative than speaking children even when speaking children's gestures were considered. Thus, children benefit from iconic aspects of language but iconicity modulates spatial language development differentially when it is part of a spoken versus a sign language. Finally, both signing and speaking children were less informative than adults, pointing to the challenge of this spatial domain in conceptual and linguistic development regardless of the modality of expression.

2.1. Introduction

Children, from early on, see and interact with several objects surrounding them (e.g., a fork next to a plate) and they need to communicate about these objects and the spatial relations between them. In doing so, children need to learn how to map the linguistic expressions in their specific languages to spatial relations. Previous work has investigated spatial language development in children learning different spoken languages that show considerable variability in encoding spatial relations (e.g., Bowerman, 1996a, 1996b; Johnston & Slobin, 1979). However, it is not known whether development of spatial language can be modulated by spatial expressions that have visually motivated form-meaning mappings (i.e., iconicity) as in the case of sign languages and/or co-speech gestures. In this study, we aim to investigate whether iconic affordances of visually motivated expressions provide an advantage in learning to map spatial language onto spatial relations in the domain of Left-Right relations– a domain known to be challenging for children learning spoken languages due to its conceptual complexity. To do so, we compare expressions of Left-Right relations by deaf child and adult signers to hearing child and adult speakers by taking into account not only speech but also co-speech gestures.

A substantial amount of research across many spoken languages has shown that communicating about space is an early developing skill. While some spatial terms such as *In-On-Under* emerge already at around 2 years of age (Johnston & Slobin, 1979), others such as those requiring viewpoint, take longer to emerge (Grigoroglou et al., 2019; Johnston & Slobin, 1979; Landau, 2017; Sümer, 2015). Particularly for the relations between objects located on the lateral axis, speaking children frequently produce under-informative descriptions with missing (e.g., *Side*, *Next to*) or incorrect spatial information (e.g., *Front*) instead of providing uniquely referring expressions that describe the exact spatial relation (e.g., using spatial nouns such as *Left-Right*; Sümer et al., 2014). This has been attributed to the delays in the development of a cognitive understanding of Left-Right spatial relations between the objects (Benton, 1959; Corballis & Beale, 1970; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996).

However, recent research has shown that children acquiring sign languages might have an advantage in encoding such cognitively challenging spatial relations. For instance, signing children learn to encode Left-Right relations much earlier (around age 5) than their speaking peers (not until age 8) possibly due to the visually motivated expressions in sign languages (Sümer et al., 2014). Nevertheless, speaking children also use visually motivated expressions, such as iconic gestures, while talking about space (e.g., Furman et al., 2006, 2010, 2014; Göksun et al., 2010; Özyürek, 2018; Özyürek et al., 2008; Iverson & Goldin-Meadow, 1997). It is not known whether signing children would still display sign advantage when speaking children's not only speech but also iconic co-speech gestures are taken into account.

The idea that variation in language modality might modulate spatial language development is in line with the view suggesting language development not only merely reflects and builds on the cognitive development of space, and instead, children can tune into language-specific variation in their language input early on (e.g., Bowerman, 1996a, 1996b) showing that linguistic factors also play a role in spatial language development. Multimodal variation in language input could be one of the language-specific encoding possibilities that might interact with cognitive development.

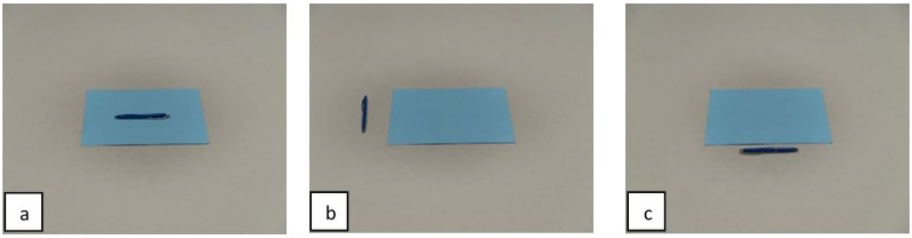
In this paper, by taking a multimodal approach to the development of spatial language, we investigate whether visual modality provides linguistic and expressive tools for children and adults to convey more information than speech. Particularly, we investigate whether sign language advantage persists even when speaking children's gestures are considered for the first time in the literature. To do so, we study child and adult signers of Turkish Sign language (Türk İşaret Dili [TİD]) and child and adult speakers of Turkish. Moreover, we compare descriptions in sign not only to descriptions in speech but also to speech-gesture combinations. In the sections that follow, we first describe the linguistic expression of locative relations specifically focusing on Left-Right in speech, sign, and co-speech gestures and with a specific focus on Turkish and TİD. Next, we review the literature on the development of Left-Right in speech, sign, and co-speech gestures. Based on this literature, we derive a set of predictions on whether visual modality of expression modulates the development of spatial language use in childhood and whether these patterns carry into adulthood.

2.1.1. Linguistic Encoding of Locative Relations

The linguistic encoding of locative spatial relations requires the mention of Figure and Ground objects as well as the spatial relation between them. In a spatial configuration, the Figure refers to the smaller and foregrounded object, which is located with respect to a backgrounded, and usually bigger object, known as the Ground (Talmy, 1985). Figure 12 depicts various locative spatial relations between the pen (Figure) and the paper (Ground). Descriptions of locative spatial relations can vary in terms of requiring the viewpoint of the observer. This especially manifests itself in cases where Ground objects do not have intrinsic features, and thus require speakers to consider a viewpoint to assign spatial terms. In Figure 12a, the spatial relation between the objects is independent of the viewpoint of the observer. However, in viewpoint-dependent relations, such as Left-Right (Figure 12b) or Front-Behind (Figure 12c), the spatial relation between the objects depends on the viewpoint of the observer (see Martin & Sera, 2006 for a discussion; see also Landau, 2017; Levinson, 2003). For Front-Behind, informational cues such as visibility (in the case of Front) and occlusion (in the case of Behind) provide information for the asymmetrical relationship that helps distinguish the two spatial relations from each other (Grigoroglou et al., 2019). The case of Left-Right, however, does not contain any informational cues to distinguish them across each other and remains to be two categorically distinct symmetrical spatial layouts. The current study focuses on the latter (i.e., Left-Right) in which language users need to be explicit in their descriptions to be informative. Below, we describe how Left-Right relations between objects can be encoded informatively in speech, sign, and co-speech gestures.

Figure 12

Objects in viewpoint-independent (a) and viewpoint-dependent (b&c) spatial configurations.



2.1.2. Linguistic Encoding of Space in Speech, Sign and Co-speech Gestures

2.1.2.1. Speech

In encoding locative spatial relations, speech transforms visual and three-dimensional experiences into categorical linguistic forms that have an arbitrary relationship to their meaning. For instance, in order to describe the spatial relation between the pen and the paper in Figure 12b, English speakers might rely on prepositional phrases with *Left* or *Right* spatial terms – depending on their viewpoint. Alternatively, in order to describe the spatial relation between the objects in the same picture, English speakers may use general spatial terms such as *Next to*. However, the latter description might be under-informative in certain contexts to distinguish between two categorical layouts, such as Left versus Right, because it fails to specify the exact spatial relation between the objects compared to expressions using *Left-Right*.

In this study, following Sümer (2015), we focus on descriptions in Turkish. In Turkish, spatial relations are encoded through postpositions by using spatial nouns (i.e., *Sağ* 'Right') in morphologically complex ways. In doing so, a locative case marker (*-de/-da*) is attached to these spatial nouns to indicate the location of the Figure object in relation to the Ground object. In addition, the Ground object is also inflected for a possessive marker (*-in/-ın*) so that the locative marker can be attached to it (see section 1.1.2.2 for more details).

For describing the picture in Figure 12b in an informative way (i.e., to distinguish Left from Right), Turkish speakers use *Sol* 'Left'. Similarly, for describing a contrastive spatial relation between these objects (i.e., where the pen is to the right of the paper), Turkish speakers use *Sağ* 'Right'. Alternatively, Turkish speakers can also use a general relational noun *Yan* 'Side'. This general relational noun in Turkish (unlike *Next to* in English) can be used to refer to any side of an object, including its Front and Back. Thus, when *Yan* 'Side' is used, it is rather under-informative and cannot distinguish one viewpoint-dependent relation from another viewpoint-dependent relation. Therefore, in Turkish, Left-Right relations are most informatively described when specific spatial nouns are used (i.e., *Sağ* 'Right' - *Sol* 'Left' instead of *Yan* 'Side'). It should be noted that Turkish speakers typically describe viewpoint-dependent relations from their viewpoint (Sümer, 2015). More information regarding the descriptions in Turkish is provided in the coding section.

2.1.2.2. Sign

In encoding locative spatial relations, sign languages incorporate iconic linguistic forms that bear visually motivated links to their meanings. The most frequent iconic form for describing spatial relations, including Left-Right, is through the use of morphologically complex classifier constructions, as shown in Figure 13c (Emmorey, 2002; Janke & Marshall, 2017; Perniss et al., 2015a; Supalla, 1982; Zwitserlood, 2012). In these constructions, the location of the hands encodes the location of the objects with respect to each other in signing space, while the handshape encodes objects' shape information. The position and the location of the hands in signing space communicate information about the location of the objects (e.g., Emmorey, 2002; Perniss, 2007; Supalla, 1982; Zwitserlood, 2003) and the classifiers themselves are expressed by handshapes that *classify* entities by representing their salient characteristics, predominantly size and shape features (Emmorey, 2002; Supalla, 1982; Zwitserlood, 2003, 2012). Morphological complexity in these forms is argued to be due to several factors such as the use of classifier handshapes (Bernardino, 2006; Brentari et al., 2013; Kantor, 1980; Morgan et al., 2008; Slobin et al., 2003; Supalla, 1982; Tang et al., 2007), the use of a location morpheme by placing hands on sign space (Schick, 1990; Zwitserlood, 2003), and representing the relative locations of Figure and Ground objects simultaneously in a classifier construction (Supalla, 1982; Slobin et al., 2003; Engberg-Pedersen, 2003; Tang et al., 2007; Morgan et al., 2008).

To illustrate, while describing the spatial relation between the cup and the toothbrush, signers first introduce the lexical signs for the cup (Figure 13a) and the toothbrush (Figure 13c), and later they choose classifier handshapes to indicate the size and shape of these two objects (e.g., Figure 13d). More specifically, signers choose a round handshape to represent the round nature of the cup and an elongated handshape (i.e., index finger) to represent the shape of the toothbrush. Later, they position their hands in the signing space in a way analogue to the real space. Thus, the representation of spatial relations between objects on the signing space maps onto the exact spatial relation between the objects in real space from a specific viewpoint (mainly signer viewpoint). For instance, if the toothbrush was located on the right of the cup, then, the signer would have positioned her handshape with an index finger for the toothbrush at the right side of the handshape depicting the location of the cup from her point of view.

Figure 13

An example of a classifier construction from a TİD signer to encode the spatial relation between the cup and the toothbrush.

RH:	GLASS	CL(round)$_{Loc}$	---- HOLD ----	---- HOLD ----
LH:	-----	-----	TOOTHBRUSH	CL(long)$_{Loc}$

'There is a cup. There is a toothbrush. The toothbrush is to the left of the cup.'

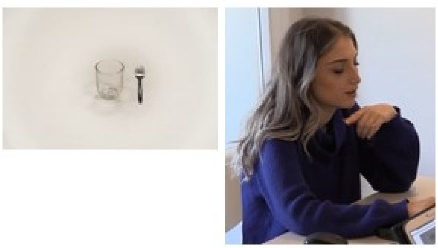
In addition to classifier constructions, signers can use other linguistic forms – albeit less frequently – to express the spatial relation between objects. These include relational lexemes (Arık, 2003; Sümer, 2015), tracing the shape of the objects and locating them on the signing space (Perniss et al., 2015a), pointing to indicate the object's location in the signing space (Karadöller et al., 2021 as reported in **Chapter 3**), and lexical verb placements (Newport, 1988) (See coding section and Figures 19, 20, 21 for more details). Similar to classifier constructions, all of these linguistic forms give iconic information about the relative spatial locations of the objects with respect to each other from signers' perspective. In this sense, they are almost always informative and differ from the under-informative expression in spoken languages (e.g., *Yan* 'Side' in Turkish or *Next to* in English), which fail to distinguish between the two symmetrical layouts. Expressions of spatial relations in sign then can be also considered more informative than speech forms (e.g., *Left-Right*) due to their iconicity.

2.1.2.3. Co-speech Gestures

Visual modes of expressions allowing iconic and analogue encodings are not specific to sign languages. These types of expressions can be found in spoken languages in the form of co-speech gestures (Kendon, 2004; Kita & Özyürek, 2003; McNeill, 1992, 2005). Co-speech gestures can be used to indicate locations of objects in gesture space in an analogue manner and might help convey more information about spatial relations than speech alone due to iconic affordances of visual modality. For instance, when talking about locations in space, speakers sometimes encode space in an ambiguous way (e.g., *Here* or *There*) while also using gestures to indicate specific locations in space (McNeill, 2005; Peteers & Özyürek, 2016). Figure 14 exemplifies the use of a directional pointing gesture used with speech. In this example, although speech fails to give information regarding the exact spatial relation between the objects, the directional pointing gesture to the right gestural space indicates that the fork is on the right side. In such descriptions, gestures might serve as a helpful tool during communication by disambiguating information conveyed in speech (McNeill, 1992; see more examples in the coding section) and thus contribute to linguistic encoding of the spatial relation. However, such gestures might also express similar information to that expressed in speech such as pointing to the right gestural space while saying *Right* in speech.

Figure 14

An example from a Turkish speaker using a pointing gesture towards the right while mentioning "Side" in speech.



Bardağ-ın	*yan-ın-da*	*çatal*	*var*
Cup-GEN	*side-POSS-LOC*	fork	there-is

'There is a fork at the side of the cup'

Notes. The underlined word denotes the speech that gesture temporally overlaps with. The description is informative when both speech and gesture are considered.

2.1.3. Development of Linguistic Encoding of Space in Speech, Sign, and Co-speech Gestures

2.1.3.1. Speech

Previous research has revealed some regularities in learning to express spatial relations across spoken languages. Specifically, children first encode spatial terms for viewpoint-independent relations (i.e., *In-On-Under*) starting around age 2 (Casasola, 2008; Casasola et al, 2003; Clark, 1973; Johnston & Slobin, 1979) followed by viewpoint-dependent ones such as Front-Behind (Durkin, 1980; Grigoroglou et al., 2019; Johnston & Slobin, 1979; Piaget & Inhelder, 1971). Linguistic expressions for Left-Right, however, appear latest and are found to be delayed for children acquiring a spoken language even until 10 years of age (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015). This order has been hypothesized to reflect non-linguistic conceptual development of space (e.g., Clark, 2004; Johnston, 1985, 1988).

Learning to encode of Left-Right is attributed to a two-step process. First, children develop a conceptual understanding of their own Left-Right and map relevant spatial terms to refer to their own body (Howard & Templeton, 1966). As a next step, they map these spatial terms on other people's left and right hands/legs (Howard & Templeton, 1966; Piaget, 1972). Encoding Left-Right relations between objects appears even later (e.g., Abarbanell & Li, 2021; Sümer et al., 2014). Even though speaking children start using *Left-Right* spatial terms at around age 10, they still use them less frequently compared to adults and often provide incorrect or missing information in their speech alone descriptions (see Abarbanell & Li, 2021 and Sümer et al., 2014 for the use of alternative spatial terms, such as Front, for describing Left-Right). This has been attributed to the symmetrical nature of Left-Right, which is hard to be distinguished and can be encoded only categorically in speech.

2.1.3.2. Sign

Recent research in sign language acquisition raises the possibility that the above-mentioned developmental trend of learning to encode Left-Right in speech might not simply be a reflection of a challenge in cognitive development. Rather, it is specific to the development of spoken expressions that requires arbitrary and categorical terms to express Left-Right relations. Unlike arbitrary encodings of spoken expressions, iconic affordances of sign languages can facilitate children's encoding of Left-Right relations. Empirical support for this claim comes from a study conducted by Sümer et al. (2014) showing that signing children of TİD can produce expressions of Left-Right relations in adult-like ways earlier than Turkish-speaking children do so in speech. Importantly, this advantage has not been found for other spatial relations, such as In-On-Under (Sümer & Özyürek, 2020) that are less challenging to acquire despite the differences between Turkish and TİD in terms of typology, morphological complexity, and lexical diversity. Hence, the advantage found for signing children in encoding Left-Right seems to be best explained by the iconic affordances of sign languages that allow direct mappings of the spatial relation onto the signing space or on the coordinates of the body that possibly ease the encoding of cognitively challenging spatial relations (Karadöller et al., 2021 as reported in **Chapter 3**; Sümer, 2015; Sümer et al., 2014 for TİD; Manhardt et al., 2020 for Sign Language of the Netherlands). Therefore, modality-specific affordances of sign languages (i.e., iconicity) might interact with cognitive development and in turn might ease the acquisition of cognitively challenging spatial relations earlier in sign languages than in spoken languages. This is reminiscent of claims highlighting the importance of language-specific encodings as factors shaping spatial language development rather than merely reflecting cognitive development of space (e.g., Bowerman, 1996a, 1996b).

2.1.3.3. Co-speech Gestures

Similar to sign language encodings, iconic affordances of co-speech gestures convey visually motivated expressions of space along with speech for adults and children (see Özyürek, 2018 for a review). A few studies have found gestures to be an important indicator for the development of spatial communication (e.g., Sekine, 2009; Sauter et al., 2012). In one of these studies, Sekine (2009) investigated route descriptions of children (e.g., from school to home) in three age groups (4, 5, and 6 years). The results showed a correlation between spatial information used in speech (use of *Left-Right* terms and mention of landmarks in the route) and the spontaneous use of spatial gestures. Another study investigating descriptions of the spatial layout of hidden objects in a room found that 8-year-olds rarely encoded the spatial location of objects in speech but used gestures to convey the locations of objects when prompted to use their hands (Sauter et al., 2012). Based on this previous research, it is plausible to argue that gestures can be used as tools for spatial communication by children and might convey information about spatial relations in cases where speech is under-informative. This, however, has not been investigated for expression of Left-Right relations, in which speaking children are known to show delayed acquisition in speech.

2.2. Present study

According to the previous research summarized above, the visual modality (i.e., sign and gesture) seems to be privileged in providing informative expressions about spatial relations compared to speech due to the visually motivated form-meaning mappings. However, the role of visual modality as a modulating factor in spatial language development has not been fully explored. Limited work has compared sign to speech. However comparing sign to both speech and speech-gesture combinations could more realistically approximate spatial language development as it would capture all expressive tools available to spoken languages, including both arbitrary/categorical (i.e., auditory-vocal speech) and iconic/analogue (i.e., visual-spatial co-speech gestures) expressions (Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019). Hence, here we investigate for the first time how deaf child and adult signers and hearing child and adult speakers express Left-Right relations by comparing spatial expressions in sign not only to expressions in speech, but also considering gestures produced along with speech.

We defined informativeness in terms of whether a participant's description conveys cues in distinguishing symmetrical Left-Right relations (see Grigoroglou & Papafragou, 2019a for a similar approach in the domain of events). Informativeness depends on the context in which participants provide a uniquely referring expression that distinguish the target spatial relation between the objects compared to other potential spatial relations. In the present study, participants engaged in a communicative task in which they saw displays with 4 pictures presenting different spatial configurations of the same two objects (see Manhardt et al. 2020, 2021 for a similar procedure). Within one display, the only distinguishing feature of the pictures was the spatial configuration between the objects (see Figure 15 for example displays). One of the pictures in the display was the "target picture" to be described to an addressee who had to find it on her tablet among other pictures. The target picture was indicated by an arrow, which was only visible to the participant, but not to the addressee. The addressee did not give any feedback to the participants regarding whether or not the descriptions were correct in order to avoid leading participants to be informative in one way or another. A detailed description of the stimuli material, procedure, and coding are described in the methods section.

We made comparisons between Turkish and TİD for several reasons. First of all, these languages have been chosen as previous work established linguistic encoding patterns of spatial relations in Turkish and TİD where a sign advantage for children has been found compared to speech in encoding Left-Right relations (Sümer, 2015; Sümer et al., 2014). This allows us to build on the previous research more directly. Second, these languages were chosen because both require morphologically complex structures to encode spatial relations. Third, although not directly studied for the domain of space, Turkish has been found to be a high gesture culture in general (Azar et al., 2020). Due to these features of Turkish and based on previous work showing that gestures can be used as a tool to convey spatial information by children (Sauter et al., 2012; Sekine, 2009), we investigate whether signing children still have an advantage (see prior work by Sümer, 2015) in describing Left-Right relations in informative ways compared to speaking children even when their multimodal expressions are taken into account.

2.2.1. Predictions

We grouped our predictions into two clusters: First, for comparing sign to speech (i.e., Unimodal Descriptions), and next comparing sign to speech by also taking into account gestures (i.e., Multimodal Descriptions). In each section, we also compared the development of spatial expressions of children to adults separately for sign, speech, and speech-gesture combinations.

In unimodal descriptions, for speech, following the evidence in the literature (Clark, 1973; Sümer, 2015; Sümer et al., 2014) we expected speaking children to produce informative descriptions less frequently than adults. For sign, we expected signing children to produce informative descriptions equally frequently to signing adults as they have been found to produce adult-like expressions of Left-Right relations starting from 4 years of age (Sümer, 2015). Alternatively, signing children, similar to speaking children, might produce informative descriptions less frequently than adults despite the advantage of visual modality. This latter possibility would indicate a universal challenge in conceptual development of the spatial domain, specifically for Left-Right regardless of the modality of expression (Clark, 1973). Furthermore, when comparing sign to speech, we expected both child and adult signers to produce informative descriptions more frequently than speakers due to the affordances of visual modality that allow iconic/analogue expressions rather than rendering space into arbitrary/categorical speech forms (Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019; Taub, 2001; Taub & Galvan, 2001). This will indicate how linguistic affordances of the language that children are acquiring might interact with cognitive development of space to predict developmental outcomes (Bowerman, 1996a, 1996b).

Turning to multimodal descriptions, we predicted that if iconicity facilitates learning to encode spatial relations in informative ways, speaking children use co-speech gestures along with speech more than adults who would be mostly informative in their speech (Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry et al., 1988; Sauter et al., 2012). As a result, speaking children might be equally informative to speaking adults when their descriptions with speech-gesture combinations are considered.

When comparing speech-gesture combinations to sign, we expected speakers to be equally informative to signers for both age groups (Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019). However, it is still possible for signing children to be more informative than speaking children even when the iconic co-speech gestures are considered, considering the developmental challenge for speaking children in encoding Left-Right relations. Such a finding could be due to the fact that iconic forms in sign are conventional linguistic tools (Brentari, 2010; Emmorey, 2002; Klima & Bellugi, 1979), unlike co-speech gestures which are not learned as linguistic forms but used as a composite system together with speech (Kendon, 2004; McNeill, 1992, 2005; see Özyurek & Woll, 2019 and Perniss et al., 2015b for a discussion).

A final possibility is that even if expressions in sign and co-speech gestures might be more informative than speech, both signing and speaking children could be less informative than their adult counterparts due to the cognitive complexity of Left-Right as a spatial domain.

2.3. Method

The methods reported in this study have been approved by the Ethics Review Board of the Radboud University, Nijmegen and Survey and Research Commission of the Republic of Turkey Ministry of National Education.

2.3.1. Participants

Speaking participants consisted of 24 child (14 Female; Mean Age = 8;6; Age Range = 6;7 – 9;5) and 23 adult (14 Female; Mean Age = 35;9; Age Range = 19;8 – 50) hearing monolingual Turkish speakers. Data from 1 additional speaking child and 2 additional speaking adults were excluded from the study since they were bilingual. Additionally, data from 2 speaking children and 2 speaking adults were excluded due to having a very low number of descriptions (their average number of descriptions was more than 3 standard deviations below the group average).

Signing participants consisted of 21 children (12 Female; Mean Age = 8;5; Age Range = 6;8 – 11) and 26 adults (21 Female; Mean Age = 29;10; Age Range = 18;2 – 48;7). Data from an additional 6 signing children and 4 signing adults were excluded from the study due to failure to follow the instructions (n = 7), problems with the testing equipment (n = 1), or disruption during the testing sessions (n = 2).

We compared speaking and signing participants' ages and visual spatial cognitive abilities (i.e., Corsi Block Tapping Task Score; Corsi, 1972) to ensure similarity, separately for children and adults. To do so, we conducted Bayesian t-tests which assessed the probability of the mean difference (M_{DIFF}) greater than zero and less than zero using the R package BayesianFirstAid (version 0.1; Bååth, 2014). Signing and speaking children were similar in age (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.556, M_{DIFF} (5) < 0: p = 0.444) and in Corsi Block Tapping Task score (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.972, M_{DIFF} (5) < 0: p = 0.280). Moreover, signing and speaking adults were also similar in age (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.736, M_{DIFF} (5) < 0: p = 0.264) and Corsi Block Tapping Task score (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.866, M_{DIFF} (5) < 0: p = 0.134).

2.3.2. Materials

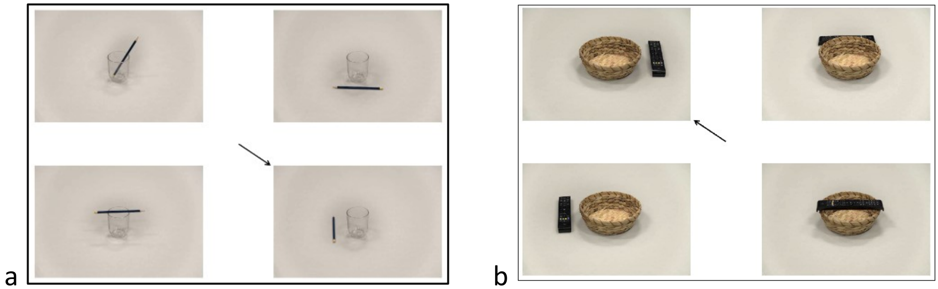
Stimuli consisted of 84 displays. Each display had 4 pictures presented in a 2 x 2 grid. Individual pictures in each display showed the same two objects in various spatial configurations. Ground objects (e.g., a glass) were always in the center of the pictures and they did not have "intrinsic" sides determined by their shape (e.g., a car has an intrinsic front but a cup does not). Figure objects (e.g., a pencil) changed their location in relation to the Ground objects. In each display, the target picture to be described was indicated by an arrow. Experimental displays (n = 28) consisted of Left-Right spatial configurations between objects (e.g., the pencil is to the *left* of the cup). In half of the experimental displays, only the target picture contained Left or Right spatial configuration between objects and all non-target pictures contained spatial configurations other than Left-Right (i.e., Non-contrast displays). In the remaining half of the experimental displays, one non-target picture contained the contrastive spatial configuration (i.e., contrast picture; if the target picture contained Left spatial configuration, contrast picture contained Right spatial configuration or vice versa) and remaining pictures contained spatial configurations other than Left-Right (i.e., Contrast displays) (See Figure 15 for example displays). The rationale for having Contrast displays in addition to Non-contrast displays was to increase the need for informativeness in describing the spatial relation between the objects in the target pictures (i.e., more need for informativeness to describe Contrast than Non-Contrast displays) in a more distinctive way to distinguish it among the other pictures in the display (see Manhardt et al., 2020, 2021 for a similar procedure).

In addition to the experimental displays, we included 56 filler displays to avoid attention to the Left-Right spatial configurations. Filler displays consisted of target pictures in Front (n = 14), Behind (n = 14), In (n = 14), and On (n = 14) spatial relations between objects.

All visual displays were piloted to ensure that both children and adults could identify and name the objects in the display. Within all 84 displays, Figure objects (e.g., pen) were presented only once. Ground objects (e.g., cup) were presented 4 times but always with other Figure objects (e.g., cup-pencil, cup-egg, cup-fork, cup-chocolate). The same Ground objects were never presented twice in a row. Moreover, the same relation between the objects as a target picture was not presented more than twice in a row to avoid biases to one type of spatial relation. There were two sets of displays with the same Ground objects but with different Figure objects. All other configurations were similar across the two sets. The order of the displays and locations of the pictures in each display were randomized across each participant.

Figure 15

Non-contrast (a) and contrast (b) experimental displays.



2.3.3. Procedure

2.3.3.1. Description task

Participants were presented with the description task after the familiarization task was completed (see details below). Trials started with a fixation cross (2000ms), followed by a display of 4 pictures (1000ms). Next, an arrow appeared (for 500ms) to indicate the target item and disappeared and 4 pictures remained on the screen (2000ms) until visual white noise appeared. Participants were instructed to describe the target picture to an addressee sitting across the table immediately after the appearance of the visual white noise. This manipulation was done to avoid children's tendency to point towards the screen to show the pictures or objects in a picture while describing. Participants were instructed that the addressee would choose the target picture on her tablet based on the participant's description. They were also aware that the addressee had the same 4 pictures but in a different arrangement in the display and without the arrow. The addressee was a confederate and pretended to choose a picture on her tablet based on the participant's description. Participants moved to the next trial by pressing the ENTER key on the keyboard. Having an addressee, albeit as a confederate, was especially important considering previous reports on children's tendencies to be under-informative in the presence of an inattentive listener or in the absence of a listener (Bahtiyar & Küntay, 2009; Girbau, 2001; Grigoroglou & Papafragou, 2019b). See Figure 7 from **Chapter 1** for the timeline of a trial in the description task.

At the beginning of the description task, participants engaged in practice trials (n = 3) and these trials were repeated if necessary. During practice trials, when participants failed to understand the task instructions, the experimenter repeated them. Both during the practice trials and throughout the experiment, the addressee did not give feedback on whether or not the description was correct in order to avoid biasing the responses in the upcoming trials but pretended to have found the right picture. When there was missing spatial information in participant's description, the addressee only asked the location of the Figure object. In such cases, speaking participants were asked for the location of the figure object (e.g., Kalem nerede? 'Where is the pencil?') in Turkish, and signing participants were asked for the location of the Figure object using the lexical sign of WHERE and the lexical sign of the Figure object found in the target picture in TİD. In order to provide consistent feedback, no other instructions were given to the participants. The addressee asked for such a clarification only once. Even if participants provided a description with missing spatial information in the second round, the addressee did not ask for further clarification and pretended to choose a picture in her tablet. Moreover, we did not provide explicit instructions for speaking participants to gesture or not. Thus, all of the gestures were spontaneously produced. Hearing adult speakers of Turkish were present as an addressee and as an experimenter for speaking participants and deaf adult signers of TİD were present as an addressee and as an experimenter for signing participants.

2.3.3.2. Familiarization task

The familiarization task was introduced before the description task. This task aimed to introduce the general complexity of the displays with the 2 x 2 grid with two objects in various spatial configurations to each other. Participants were randomly presented with one of the two sets of displays that they did not receive during the description task.

2.3.3.3. Corsi Block Tapping Task

Participants received the computerized version of the Corsi Block Tapping Task in forward order. We administered this task to ensure that speaking and signing participants have similar spatial working memory spans (Corsi, 1972). This was especially important when comparing the visuospatial abilities across signers and speakers (see Emmorey, 2002 & Marshall et al., 2015).

All the experimentation (Familiarization Task, Description Task, and Corsi Block Tapping Task) was administered via Dell laptop with software Presentation NBS 16.4 (Neurobehavioral Systems, Albany, CA). Instructions of the tasks were given orally to speaking participants or in sign to signing participants in order to avoid misunderstandings in written instructions by signers. We applied the same procedure to speakers to ensure identical experimental strategies. The description task was video-recorded from the front and side-top angles to allow for speech, sign, and gesture coding (see Figure 8 from **Chapter 1** for the general experimental setup).

2.3.4. Annotation and Coding

All descriptions produced in the description task were annotated for Target Pictures. Descriptions with speech, gesture, and sign were coded using ELAN (Version 4.9.3), a free annotation tool (http://tla.mpi.nl/tools/tla-tools/elan/) for multimedia resources developed by the Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Wittenburg et al., 2006).

First of all, we removed all trials in which participants did not attempt to describe the target picture (i.e., no attempt trials) and thus coding is based on trials that participants attempted to describe the target picture.[4] We coded descriptions in speech, gesture, and sign. Next, we formed informativeness categories first based on the information conveyed in speech, later by considering co-speech gestures along with speech, and in sign. We operationalized informativeness as whether participants' descriptions provide a uniquely referring expression to distinguish the spatial relation between the

[4] There was a very small number of cases where participants got distracted and failed to describe the target picture during the visual white noise screen. There were also a few cases where participants pressed the ENTER key twice (instead of once) to move to the next trial and consequently skipped a trial.

objects in the target picture considering the context of the displays with 4 pictures.

2.3.4.1. Speech

Speech data were annotated and coded by a hearing native speaker of Turkish. We did not have a reliability coding for speech as speech coding involved the presence of spatial terms (e.g., *Left*) that were unambiguously heard and identified by a hearing native speaker of Turkish. We grouped participants' descriptions into two categories based on whether or not the linguistic form used to encode the spatial relation in the description was informative in uniquely identifying the target picture when only speech is taken into account.

(1) *Informative in Speech*: This category consisted of descriptions that included *Sol* 'Left'- *Sağ* 'Right' spatial nouns in speech. The specific spatial terms used in these descriptions provided uniquely referring expressions that distinguish the target picture (Figure 16a).

(2) *Under-informative in Speech*: This category consisted of all the remaining descriptions as they failed to provide enough information to uniquely identify the target picture. These descriptions include the following sub-categories:

(2a) Descriptions with a general relational term (*Yan* 'Side'; Figure 16b) that failed to provide uniquely referring information that distinguished the actual spatial relation (e.g., which object is on the left side and which object is on the right side). In Turkish, *Yan* 'Side' can be also used for encoding Front and Behind spatial configuration between objects and thus fail to distinguish among Left, Right, Front, and Behind configurations in one display.

(2b) Specific spatial terms other than *Left-Right* (e.g., *Ön* 'Front'; Figure 16c). These descriptions were especially prominent for children where children tended to encode Left-Right with other spatial relations especially with *Front* (Abarbanell & Li, 2021; Sümer et al., 2014). A few cases also included spatial terms other than *Front* to describe target pictures in Left-Right spatial relations. Based on our definition of informativeness, all of these descriptions that encoded Left-Right with other spatial terms were not informative enough for the addressee to pick up the correct picture from her tablet and thus was considered under-informative.

(2c) Descriptions with missing spatial relation where participants only labeled the objects but not the spatial relation between them (Figure 16d).

Figure 16

Examples from Turkish speakers describing the target picture in Figure 15a by using (a) Left-Right spatial terms, (b) general relational term Side, (c) spatial terms other than Left-Right, (d) missing encoding of spatial relation between the objects.

(a) *Bardağ-ın sol-un-da kalem var.*
Cup-GEN left-POSS-LOC pen there_is.
'There is a pen to the left of the cup.'

(b) *Bardağ-ın yan-ın-da kalem var.*
Cup-GEN side-POSS-LOC pen there_is.
'There is a pen at the side of the cup.'

(c) *Bardağ-ın ön-ün-de kalem var.*
Cup-GEN front-POSS-LOC pen there_is.
'There is a pen to the front of the cup.'

(d) *Bardak var. Kalem var.*
Cup there_is. Pencil there_is.
'There is a cup. There is a pencil.'

2.3.4.2. Speech and Gesture

We further coded spontaneous co-speech gestures as identified by strokes (see Kita et al., 1998) produced by participants that conveyed information regarding the location of the two objects or the spatial relation between the objects. We did not take into account other types of gestures such as beat gestures.

In order to ensure reliability, 25% of the gesture data (5 Children and 5 Adults) were coded by another hearing native speaker of Turkish. There was a substantial agreement between the coders for the type of spatial gestures used to localize Figure (88% Agreement, kappa = 0. 77) and Ground (92% Agreement, kappa = 0.79) objects. All disagreements were discussed to reach a 100% agreement.

For each description, we coded gestures separately for Figure and Ground objects. These gestures included either directional pointing gestures indicating the location of the Figure or Ground Object in an analogue way (Figure 14 and 17) or iconic hand placement gestures indicating the location of the Figure and/or Ground object on the gesture space (Figure 18). Both of the spatial gesture types give spatial information about the Left-Right relations between objects from the viewpoint of the speaker, and help identify the target picture uniquely from other referents in the display. As a next step, we considered these spatial gestures on top of what has been conveyed in speech and reformed the informativeness categories for speakers creating multimodally informative categories:

(1) *Informative in speech*: This category only involved *Left-Right* spatial nouns as described above. Some of the descriptions with *Left-Right* spatial nouns also included accompanying spatial gestures in similar ways to what is expressed in speech. However, for these descriptions, spatial gestures did not add to the informativeness of the description and were considered redundant. That is, speech was already informative even without considering the gestures. Thus, they did not form a new category (see Figure 17).

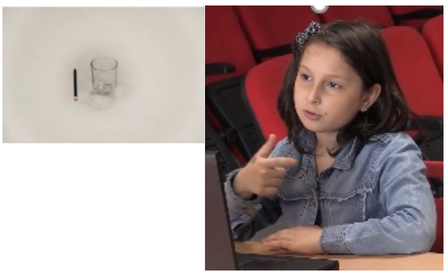
(2) *Informative in speech-plus-gesture*: This category consisted of descriptions that include general spatial term *Yan* ‘Side’ in speech together with spatial gestures. In these descriptions, spatial information missing from descriptions with *Yan* ‘Side’ in speech was conveyed via spatial gestures (see Figures 14 and 18 for examples). Thus, these descriptions were informative only when the spatial gestures were also taken into account.

(3) *Under-informative even when gestures are considered*: This category consisted of descriptions with specific spatial nouns other than *Left-Right* (e.g., *Front*; Figure 16c) as well as descriptions with missing spatial relation where participants only label the objects but not the spatial relation

between them (Figure 16d). These descriptions were still under-informative even when gestures were considered together with speech. That is, gestures did not contribute to the informativeness of the description above speech.

Figure 17

Informative in Speech description from a Turkish speaker using a specific spatial noun (Left) together with a directional pointing gesture to the left and being informative already when speech is considered.



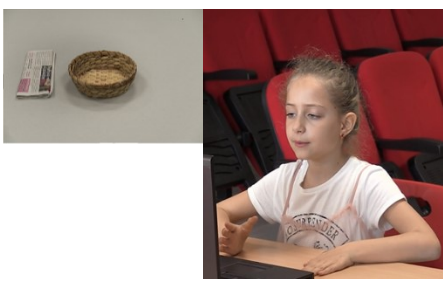
Bardağ-ın sol-un-da kalem var.
Cup-GEN left-POSS-LOC pencil there_is.
'There is a pencil to the left of the cup.

RH: Directional pointing (left)
LH: ------------------------------

Note. Underlined words denote the speech that the gesture overlapped with.

Figure 18

Informative in speech-plus-gesture description from a Turkish speaker using a general spatial noun (Side) together with iconic hand placement gestures and being informative only when both speech and gestures combined.



Sepet-in yan-ın-da gazete var.
Basket-GEN side-POSS-LOC newspaper there_is.
'There is a newspaper at the side of the basket'

RH: Iconic/placement (basket)
LH: Iconic/placement (newspaper)

Notes. Participant introduced gestures sequentially. Gesture indicating the basket (RH) performed when the participant mentioned the basket in her speech. Gesture indicating the newspaper (LH) performed when the participant mentioned the newspaper. Both gestures remained in the gesture space until the end of the sentence.

2.3.4.3. Sign

Sign data were annotated by a hearing L2 signer of TİD. The data were coded by another hearing L2 signer of TİD. Annotations and coding were checked by a trained native deaf signer of TİD. We did not have a reliability coding for sign as we only included the linguistic forms that were unambiguously approved by this signer in the final dataset.

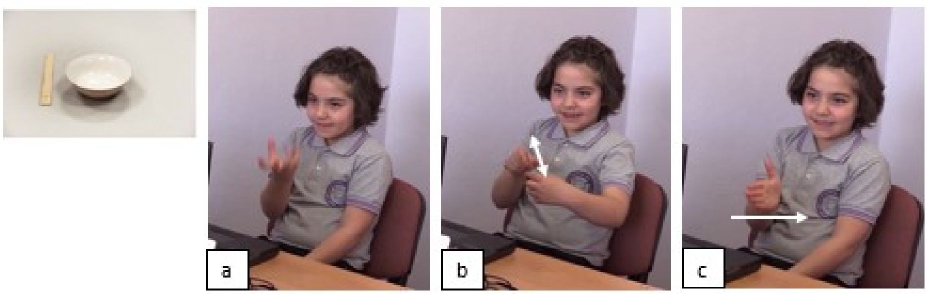
We coded descriptions for the presence of spatial relation between the objects and the type of linguistic form used to localize the Figure object in relation to the Ground object. Signers used 5 different Linguistic forms. These forms were classifier constructions (Figure 13c; see also Figures 2 and 3 from **Chapter 1**, Figure 25 from **Chapter 3**, and Figure 34 from **Chapter 4**), which is one of the most common linguistic forms to localize the Figure object in relation to the Ground object in sign languages in general (Emmorey, 2002) and also in TİD (Arık, 2013; Karadöller et al., 2021 as reported in **Chapter 3**; Sümer, 2015; Sümer, et al., 2014). They allow signers to encode information about the entities through the handshape classifications of objects (e.g., Emmorey, 2002; Janke & Marshall, 2017; Perniss et al., 2015a; Manhardt et al., 2020; Zwitserlood, 2012). Alternatively, signers also use other forms such as relational lexemes, which are the lexical signs for spatial terms used in sign languages (Arık, 2003; Manhardt et al., 2020; Figure 19 below; see also Figure 26 and 27 from **Chapter 3**); tracing the shape of the Figure object on the signing space (Karadöller et al., 2021; Figure 20 below; see also Figure 31 from **Chapter 3**); pointing to the location of the Figure object in the signing space (Karadöller et al., 2021; Figure 21 below; see also Figure 30 from **Chapter 3**); placing a lexical verb (see Newport, 1988 for the discussion of single-morpheme signs; see also Figure 32 from **Chapter 3**) in signing space to represent the Figure object on the signing space. We grouped participants' descriptions into two categories in terms of whether or not the description was uniquely informative in identifying the target picture depending on the linguistic form that is used to encode the spatial relation in sign.

(1) *Informative in Sign*: This category consisted of all of the linguistic forms mentioned above as all of these linguistic forms were describing the exact spatial relation between the objects and distinguishing the target picture uniquely from the other pictures in the display.

(2) *Under-informative in Sign:* This category included descriptions with incorrect spatial relation between the Figure and Ground objects (e.g., describing that the pen is in front of the paper, although the target picture showing that the pen is to the left of the paper), descriptions with missing spatial relation (e.g., only labeling the Figure and Ground object but not the spatial relation of the Figure object in relation to the Ground object, Figure 22), and descriptions using classifier constructions that are ambiguous due to the choice of improper handshape (e.g., using an elongated handshape to locate a round object such as a lemon).

Figure 19

Informative description in sign from a TİD signer by using a relational lexeme for Left in encoding the spatial relation between the cup and the ruler.



RH: CUP RULER LEFT

LH: ---- RULER ----

'There is a cup. There is a ruler. The ruler is to the left'

Figure 20

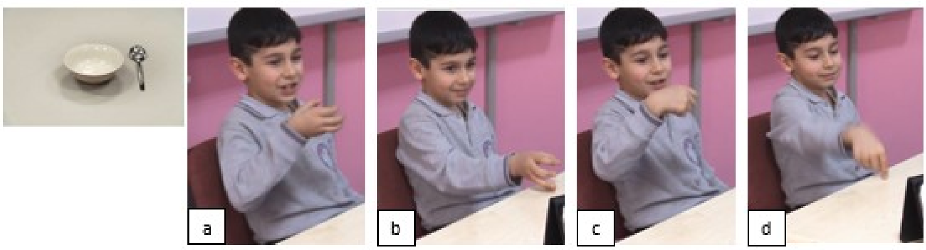
Informative description in sign from a TİD signer by tracing the shape of the Figure object on the signing space in encoding the spatial relation between the cup and the ruler.

RH:	CUP	CL(round)$_{Loc}$	CORN	Tracing(Corn)$_{Loc}$
LH:	----	----	----	Tracing(Corn)$_{Loc}$

'There is a cup. Cup is located here (Right). There is a corn. The corn is located here (Left)'.

Figure 21

Informative description in sign from a TİD signer by Pointing to the location of the spoon to locate it on the signing space in encoding the spatial relation between bowl and spoon.



RH:	CUP	CL(Round)$_{Loc}$	SPOON	Pointing(Spoon)$_{Loc}$
LH:	----	----	----	----

'There is a cup. The cup is here (Left). There is a spoon. The spoon is here (Right)'.

Figure 22

Under-informative description in sign with missing spatial relation between objects.

RH: MONEYBOX LEAF
LH: MONEYBOX LEAF
'There is a moneybox. There is a leaf.'

2.4. Results

Data presented in this section were analyzed using generalized binomial linear mixed-effects modeling (*glmer*) with random intercepts for Subjects and Items.[5] This mixed-effects approach allowed us to take into account the random variability due to having different participants and different items. All models were fit with the *lme4* package (version 1.1.17; Bates et al., 2015) in R (R Core Team, 2018) with the optimizer *bobyqa* (Powell, 2009). We did not include random slopes in any of the models because all of our models were testing between-subjects effects that cannot be added as random slopes.

2.4.1. Comparisons of Unimodal Descriptions

Here, we first compared informativeness considering information in speech only and in sign across adults and children and then across the two language groups.

[5] Display Type (Contrast, Non-contrast) was used as a fixed effect in all of the initial models, we removed it from all the models reported in this chapter as (1) it did not turn out to be significant and (2) did not improve the model fit.

2.4.1.1. Speech

First, we investigated the frequency of descriptions that were Informative in speech (i.e., *Left-Right*) across adults and children to test whether speaking children used informative descriptions in statistically similar frequencies to their adult counterparts (see left panel of Figure 23). We used a *glmer* model to test the fixed effect of Age Group (Children, Adults) on whether the descriptions were Informative in speech (1) or Under-informative in speech (0) at the item level. The fixed effect of Age Group was analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Age Group (β = 6.32, *SE* = 1.34, p < 0.001). Adults (*Mean* = 0.86; *SD* = 0.35) produced more descriptions that were Informative in speech compared to children (*Mean* = 0.32; *SD* = 0.47).

2.4.1.2. Sign

Next, we investigated the frequency of descriptions that were Informative in sign across adults and children to test whether signing children used informative descriptions equally frequently to their adult counterparts (see right panel of Figure 23). We used a *glmer* model to test the fixed effect of Age Group (Children, Adults) on whether the descriptions were Informative in sign (1) or Under-informative in sign (0) at the item level. The fixed effect of Age Group was analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Age Group (β = 2.59, *SE* = 0.49, p < 0.001). Adults (*Mean* = 0.99; *SD* = 0.11) produced more descriptions that were Informative in sign compared to children (*Mean* = 0.88; *SD* = 0.32).

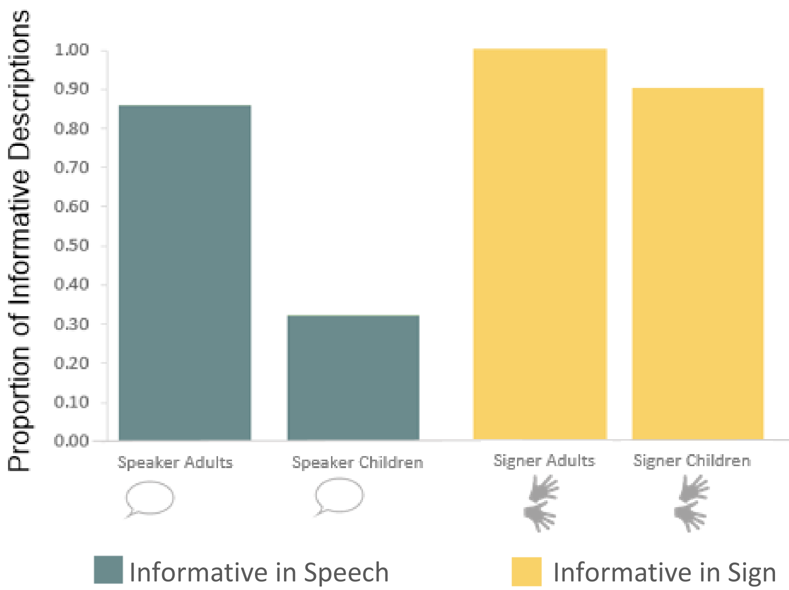
2.4.1.3. Speech versus Sign

Additionally, we investigated whether sign has an advantage over speech by comparing the frequency of descriptions that were informative across each Modality (Informative in speech versus Informative in sign) separately for children and adults (see Figure 23). Our goal was to see whether both speaking children and speaking adults were equally informative to their signing counterparts when only their speech descriptions are considered. For both children and adults, we used *glmer* models to test the fixed effect of Modality (Informative in speech versus Informative in sign) on binary values for the presence of informative descriptions (Present = 1, Absent = 0) at the item level. The fixed effect of Modality was analyzed with centered contrasts (-0.5, 0.5).

For children, the model revealed a fixed effect of Modality (β = -5.24, *SE* = 1.25, p < 0.001): signing children were more likely to produce informative descriptions in sign (*Mean* = 0.88; *SD* = 0.32) than speaking children in speech (*Mean* = 0.32; *SD* = 0.47). For adults, the model also revealed a fixed effect of Modality (β = -3.09, *SE* = 0.80, p < 0.001): signing adults were more likely to produce informative descriptions in sign (*Mean* = 0.99; *SD* = 0.11) than speaking adults in speech (*Mean* = 0.86; *SD* = 0.35). Results of the Informative in speech and in sign comparisons showed that signers, both adults and children, are more informative than their speaking counterparts.

Figure 23

Proportion of Informative descriptions across Age Groups and Modalities.



Notes. Informative in speech descriptions consist of *Left-Right* spatial nouns. Informative in Sign descriptions consist of descriptions with classifier constructions, relational lexemes, tracing, pointing, or lexical verb placement.

2.4.2. Comparisons of Multimodal Descriptions

Here, we first compared informativeness considering information in speech-plus-gesture and later in overall description (speech and speech-plus-gesture) across adults and children. Next, we compared these overall descriptions (in speech and speech-plus-gesture) to those in sign.

2.4.2.1. Speech and Gesture

First of all, we tested if children's spatial gestures help convey more information than adults that is missing in Under-Informative in speech descriptions using general noun *Yan* 'Side'. To test this, we compared the frequency of descriptions that were Informative in speech-plus-gesture across children and adults (light green bars in Figure 24). We used a *glmer* model to test the fixed effect of Age Group (Children, Adults) on whether the descriptions were Informative in speech-plus-gesture (1) or not (0) at the item level. The fixed effect of Age Group was analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Age Group (β = 2.94, *SE* = 0.70, $p < 0.001$). Children (*Mean* = 0.45; *SD* = 0.46) produced more descriptions that were Informative in speech-plus-gesture compared to adults (*Mean* = 0.08; *SD* = 0.26).

Next, we tested whether children were overall equally Informative to adults when their speech, as well as their speech with gestures, are considered. This comparison combined descriptions that were Informative in speech (dark green bars in Figure 24) and descriptions that were Informative in speech-plus-gesture (light green bars in Figure 24). We used a glmer model to test the fixed effect of Age Group (Children, Adults) on binary values for the presence of informative descriptions (Present = 1, Absent = 0) at the item level. The fixed effect of Age Group was analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Age Group (β = 1.73, *SE* = 0.52, $p < 0.001$): adults (*Mean* = 0.94; *SD* = 0.24) were more likely to produce overall informative descriptions (in speech and in speech-plus-gesture) than children (*Mean* = 0.77; *SD* = 0.42).

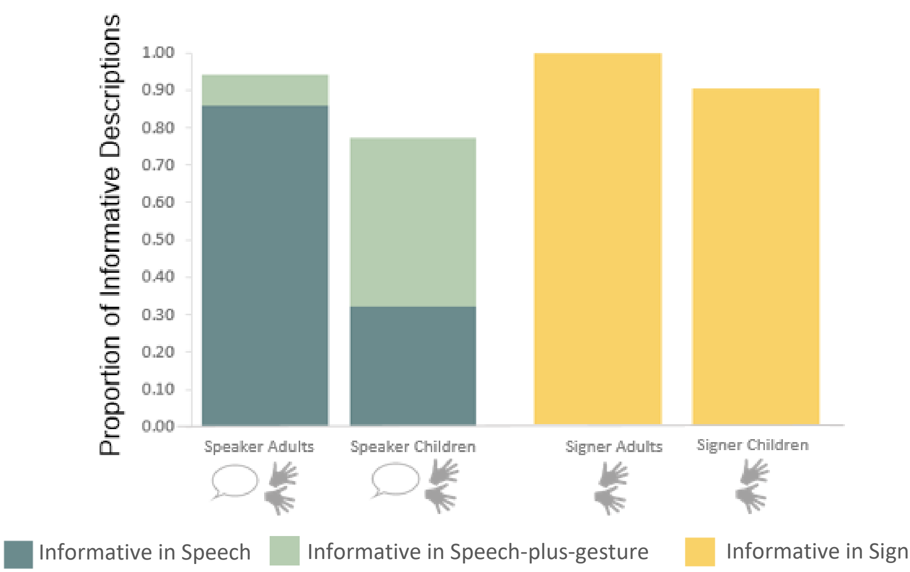
Thus, although children were more likely to use descriptions that were Informative in speech-plus-gesture (as shown by the first analysis above) than adults, overall, they were still less Informative than adults when descriptions that were Informative in speech and descriptions that were Informative in speech-plus-gesture were considered together.

2.4.2.2. Speech and Gesture versus Sign

Finally, we compared overall Informative descriptions. This analysis included both descriptions that were Informative in speech and descriptions that were Informative in speech-plus-gesture. Our goal was to see whether both speaking children and speaking adults were equally informative to their signing counterparts when their gestures are considered along with speech (light green and dark green bars compared to yellow bars in Figure 24). For both children and adults, we used *glmer* models to test the fixed effect of Modality (Informative in speech and Informative in speech-plus-gesture combined versus Informative in sign) on binary values for the presence of informative description (Present = 1, Absent = 0) at the item level. The fixed effect of Modality was analyzed with centered contrasts (-0.5, 0.5). For children, the model revealed a fixed effect of Modality ($\beta = 1.78$, $SE = 0.54$, $p < 0.001$: signing children (*Mean* = 0.88; *SD* = 0.32) were more likely to produce informative descriptions than speaking children (*Mean* = 0.77; *SD* = 0.42). For adults, the model did not reveal a fixed effect of Modality (β = 0.74, SE = 0.46, p = 0.105): signing (*Mean* = 0.99; *SD* = 0.11) and speaking (*Mean* = 0.94; *SD* = 0.24) adults were likely to produce informative descriptions in statistically similar frequencies. Thus, when we take into account co-speech gestures of adult speakers, they become equally informative to signers. However, for children, although Informative speech-plus-gesture descriptions increased the number of overall Informative descriptions, they were still not as informative as signing children.

Figure 24

Proportion of Informative descriptions across Age Groups and Modality.



2.5. Discussion

In this study, we investigated whether the modality of expression influences the informativeness of spatial expressions in children and adults. To our knowledge, this is the first study to investigate the development and adult-like uses of spatial language with a multimodal perspective by taking spatial co-speech gestures into account and comparing descriptions in sign not only to speech but also to speech-gesture combinations. Results showed that although gestures help increase the informativeness of spatial descriptions compared to information in speech for speaking children, they are still not as informative as in sign. Overall, this study shows that both the language-specific factors such as modality of expression (e.g., Bowerman, 1996a, 1996b) as well as cognitive factors such as challenges in learning to encode Left-Right (Clark, 2004; Johnson, 1985, 1988) shape spatial language development. Results point to an intricate interplay between these two factors. That is, we showed on the one hand visually-motivated linguistic forms (i.e., sign and gesture) might facilitate the language development of space above and beyond speech. We showed on the other hand spatial language development is still influenced by the cognitive complexity of the spatial expression as both signing and speaking children are less informative than adults regardless of the modality of expression in speech, sign, or speech-gesture combinations.

2.5.1. Sign has an Advantage over Speech both for Children and Adults

Comparisons across modalities revealed that signers were more Informative than speakers for all age groups when sign was compared to speech. This can be attributed to the facilitating effect of iconicity of sign language expressions providing more information compared to expressions in speech (see Slonimska et al., 2020; Taub, 2001 for adults). Our findings extend this facilitating effect to children and to the domain of space, specifically for Left-Right. This finding also provides important contributions to our understanding of the development of spatial language use in speech and sign. Turkish and TİD not only differ in terms of typology and morphological complexity but also in the modality of expression. Despite these linguistic differences, development of some spatial relations such as In-On-Under appear at similar ages for signing and speaking children (Sümer & Özyürek, 2020). By contrast, encoding of Left-Right differs between signing and speaking children, pointing to a complex interplay between modality of expression, cognitive and linguistic development of space (see also Sümer et al., 2014).

2.5.2. Gesture Enhances Informativeness of Spoken Expressions More for Children than for Adults

When we considered multimodal descriptions of speakers, we found that both children and adults produced descriptions that were Informative in speech-plus-gesture where spatial gestures disambiguated the descriptions that were Under-informative in speech with *Side* and this trend was more prominent for children than adults. This is reminiscent of previous findings from other domains showing that gestures can help clarify the meaning of *Side*. For instance, Cook et al. (2013) experimentally manipulated gesture use while teaching children how to solve math equations. Manipulation consisted of either using gestures that refer to the two sides of the math equation whenever *Side* is uttered or saying *Side* without using any gestures. Results showed that using gestures during teaching sessions helps children solve the math equation correctly and form better conceptual representations. Together with the findings of Cook et al. (2013), our findings provide evidence that the use of gestures is an important tool for clarifying under-informative speech (see also Kelly, 2001). Moreover, we extend this finding to the production domain and to situations where participants were not explicitly instructed to gesture (Sauter et al., 2019) since all of the gestures elicited in our study were spontaneously generated. Here, the frequent use of spontaneous gestures by Turkish speaking children and adults could be a reflection of Turkish being a high gesture culture (Azar et al., 2020), hence raises possibilities for further investigations in other high (e.g., Italian) and low (e.g., Dutch) gesture cultures.

Moreover, we showed that children could communicate Left-Right spatial relations between two objects informatively through co-speech gestures before communicating them informatively in speech. This suggests that by age 8, children have some conceptual understanding of the Left-Right spatial relations, yet they fail to map arbitrary/categorical linguistic forms in speech onto these conceptual representations. In these instances, gestures could act as a medium for representing already established spatial concepts that fail to surface in speech. These instances were very rare in adult language as adults could map *Left-Right* spatial terms to these concepts. We provide additional evidence to the literature on gestures preceding speech for the domain of space which was already established for several other domains (Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry et al., 1992; Sauter et al., 2012). Together, our findings highlight the centrality of the gestures and the importance of considering children's multimodal encodings in assessing their pragmatic (i.e., informativeness; Grigoroglou et al., 2019) and cognitive development (Hermer-Vasquez et al., 2001).

2.5.3. Signed Descriptions are More Informative even when Gestures are considered for Children but not for Adults

Turning to the descriptions in which spatial gestures are considered together with speech in comparison to description is sign, contrary to our prediction, signing children continued to be more informative than speaking children. This can be attributed to having visual modes of expressions as conventional linguistic forms for sign languages (Brentari, 2010; Emmorey, 2002; Klima & Bellugi, 1979). Conversely, co-speech gestures are not learned as part of the language, rather only as a composite system together with speech (Kendon, 2004; McNeill, 1992, 2005; see Perniss et al., 2015b for a discussion). Accordingly, lack of conventionality which leads to inconsistencies in exposure and experience with gestures might have facilitated the informativeness of spatial expressions of speaking children to a lesser extent compared to signing children.

Nevertheless, the same comparison across signing and speaking adults did not reveal a sign advantage. Even though speaking adults lagged behind signing adults in informativeness when sign was compared to speech, considering co-speech gestures together with speech represented speaking adults on equal grounds to their signing counterparts. Thus, visual modality seems to be an important tool for increasing the informativeness of the spatial descriptions even in the final stages of language development, namely adulthood. This finding highlights the importance of considering multimodal expressions present in spoken languages, especially when making comparisons across sign and spoken languages (Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019).

2.5.4. Left-Right Remains to be a Challenging Spatial Domain for Children Even When Visual Modality is considered

Consistent with previous work showing that speaking children are late to produce *Left-Right* spatial terms between objects, we found that speaking children were less Informative in speech than their adult counterparts (Abarbanell & Li, 2021; Clark, 1973; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). With this finding, we underline the robustness of this effect, also considering the fact that compared to a previous study (Sümer et al., 2014) the current study used a more balanced and controlled set of stimuli and more participants.

Nevertheless, contrary to our initial expectation, considering visual modality of expression as in sign or co-speech gestures did not equate children to adults in terms of informativeness of Left-Right expressions. That is, signing children who only used visual modes of expressions were less informative than signing adults. Likewise, when we consider co-speech gestures together with speech, speaking children continued to be less informative than speaking adults. This suggests an intricate interplay between language development, cognitive development, and the visual modality of representation. For instance, on the one hand, spatial gestures contribute to the informativeness of the descriptions for children more than adults, on the other, this contribution is not sufficient for speaking children to reach adult levels of informativeness and they were still less informative than their signing peers.

Together, these results speak for the general claim that the spatial domain, especially Left-Right, is challenging for children (Abarbanell & Li, 2021; Clark, 1973; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014) and extend the previous literature showing that this challenge is present regardless of the modality of communication.

2.6. Conclusion

In summary, development of spatial language seems to be the result of a complex interaction between linguistic and cognitive development of space. On the one hand, visual modality of expression, in sign or gesture can modulate the development of spatial language in signers and speakers indicating how linguistic factors play an important role in this interaction (e.g., Bowerman, 1996a, 1996b). On the other hand, the facilitating effect of sign was stronger than that of co-speech gestures in conveying informative spatial descriptions. Having conventional iconic expressions as linguistic forms in sign languages, unlike gestures that are not learned as linguistic forms but as composite utterances with speech, might have facilitated the development of informativeness in Left-Right descriptions of signing children more than speaking children. However, the facilitating impact of sign was not present in adults when considerin speech-gesture combinations of speakers, suggesting that sign advantage appears mostly during childhood. Finally, both signing and speaking children were less informative than adults even with the advantage of visual modality allowing iconic descriptions, pointing to the challenge of spatial domain in conceptual and linguistic development (Clark, 1973; Johnston, 1985, 1988). Results of the present study call for investigations in other languages, bilinguals, and cultures (e.g., low-gesture cultures) and on different aspects of language development to unravel how cognitive and linguistic (e.g., modality of expression) factors interact and determine the outcomes for developmental milestones.

Chapter 3: Effects and Non-Effects of Late Language Exposure on Spatial Language Development: Evidence from Deaf Adults and Children

This chapter is based on:

Karadöller, D. Z., Sümer, B., & Özyürek, A. (2021). Effects and non-effects of late language exposure on spatial language development: Evidence from deaf adults and children. *Language Learning and Development*, *17*, 1-25.

Karadöller, D. Z., Sümer, B., & Özyürek, A. (2017). Effects of delayed language exposure on spatial language acquisition by signing children and adults. In G. Gunzelmann, A. Howes, T. Tenbrink, & E. Davelaar (Eds.), *Proceedings of the 39th annual conference of the cognitive science society (CogSci 2017)* (pp. 2372-2376). Austin, TX: Cognitive Science Society.

Abstract
Late exposure to first language, as in the case of deaf children with hearing parents, hinders the production of linguistic expressions, even in adulthood. Less is known about the development of language soon after language exposure and if late exposure hinders all domains of language in children and adults or whether this is dependent on the linguistic and cognitive complexity of the concepts to be expressed. We investigated this question in the development of spatial language. We compared late signing adults and children (Mean Age = 8;5) 2 years after exposure to Turkish Sign Language (*Türk İşaret Dili* [TİD]) to their age-matched native signing peers in expressions of two types of locative relations that are acquired in certain cognitive developmental order: viewpoint-independent spatial relations (i.e., In-On-Under) preceding viewpoint-dependent spatial relations (i.e., Left-Right). Results show that late signing children and adults differed from native signers in their use of linguistic devices for viewpoint-dependent relations but not for viewpoint-independent relations. These effects were also modulated by the morphological complexity of the linguistic expressions. Late sign language exposure hinders the development of spatial language use in children and adults but these effects are not absolute but are modulated by cognitive and linguistic complexity, pointing to an intricate interplay of linguistic and cognitive factors in spatial language development.

3.1. Introduction

The majority of studies aiming to understand linguistic and cognitive factors giving rise to language development uses data from children who are acquiring language in a more typical circumstances. That is, children who are exposed to a language early on from their caregivers. Unfortunately, this is not the case for many deaf children. Most deaf children are born to hearing parents (Mitchell & Karchmer, 2004) and thus they lack immediate access to a conventional language – even with hearing aids which may not provide enough access to the surrounding spoken language and do not always result in optimal speech outcomes (see Hall et al., 2019). For these children, the first exposure to a conventional language can be in the form of a sign language after entering a school for the deaf at around 6 years of age or even later. As a result of such a delayed exposure to language, these children (i.e., late signers) learn a sign language quite late compared to deaf children with deaf parents (i.e., native signers) who are exposed to a sign language from birth. The current study investigates such atypical cases of language acquisition which can shed light and give unique insights into the complex interplay between cognitive and linguistic development in ways that may not be possible by studying children who are acquiring language in a more typical circumstances.

Here, we investigate the effects of late sign language exposure on the development of spatial language, and specifically on the expressions of locative spatial relations. We focus our investigation on the effects of late sign language exposure on the acquisition of two categorically distinct spatial relations that are acquired in a certain order due to cognitive development: a) spatial expressions that are not dependent on the viewpoint of the viewer (e.g., viewpoint-independent as in In-On-Under) and b) spatial expressions that are dependent on the viewpoint of the viewer (e.g., viewpoint-dependent as in Left-Right; see Martin & Sera, 2006 and Landau, 2017 for a discussion).

This study has the potential to shed some light on the development of spatial language in relation to the influence of linguistic and cognitive factors. That is, results might reveal to what extent linguistic factors mediate the development of spatial concepts (e.g., Bowerman, 1996a, 1996b) and how an independently developing cognitive understanding of space shapes language development (e.g., Clark, 2004; Johnston, 1985, 1988). To the extent cognitive representations of space develop independent of language, late signers will have similar linguistic expressions to their native signing peers soon after exposure to a conventional language. However, if cognitive representations of space are to a large extent dependent on linguistic exposure, late signers will lag behind their native signing peers. Spatial language development might also be shaped by an interaction of the cognitive complexity of the spatial domains mentioned above as well as the morphological complexity of linguistic forms used to express spatial relations. That is, late exposure could hinder the acquisition of morphologically complex linguistic structures only when encoding cognitively complex spatial relations (i.e., viewpoint-dependent) but not cognitively simpler ones (i.e., viewpoint-independent).

All of the late signers in our study, both children and adults, have been exposed to Turkish Sign Language (*Türk İşaret Dili* [TİD]) only when they started going to a school for the deaf at around 6 years of age. Additionally, at the time of testing signing children had 2 years of exposure to a sign language. Before this time, they had no access to a conventional language in the form of sign or speech but only used gestural communication at home with their hearing non-signing parents (i.e., so-called homesign situations; Goldin-Meadow, 2005; see also Gentner et al., 2013 for the Turkish context). In order to see whether such deaf children and adults' acquisition of two types of locative expressions are influenced by late language exposure, we compare their expressions to age-matched native signers who have been exposed to a sign language from birth onwards by their deaf signing caregivers. This comparison relies on the data we analyzed in our previous work on the development of spatial language patterns by native signing children and adults using TİD (see Sümer, 2015; Sümer & Özyürek, 2020). This comparison helps us see which aspects of language can be easily learned or not in late exposure and when the cognitive developmental stage is the same across native and late signers based on their age.[6]

3.1.1. Linguistic Encoding of Locative Relations in Sign Languages

Sign languages in general have two main ways to encode locative relations. The most frequent way for describing locative relations is through the use of morphologically complex classifier constructions (Perniss et al., 2015a;

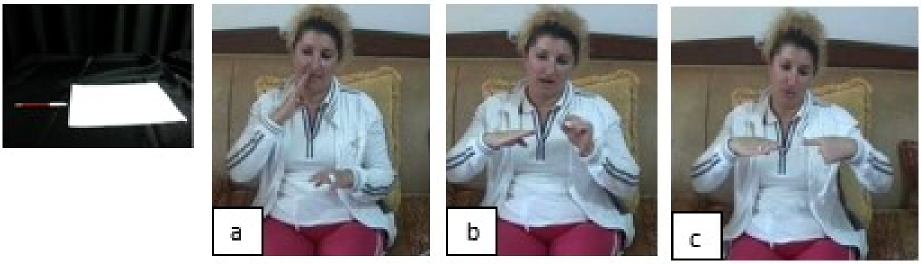
[6] In this study, we did not compare the visual-spatial cognitive abilities of native and late signers. We controlled this in **Chapter 5.**

Zwitserlood, 2003, 2012), as shown in the 3rd still of the example below (Figure 25). In these constructions, the location of the hands encodes the location of the referents, while the handshape encodes referent type by classifying it in terms of certain semantic features such as size and shape (Emmorey, 2002; Perniss et al., 2015a; Supalla, 1982; Zwitserlood, 2012). These forms incorporate the use of iconic mappings of referent features to handshapes and space-to-space mappings between the real space to signing space (Perniss, 2007). The position and the location of the hands in signing space communicate information about the location of the objects (Emmorey, 2002; Perniss, 2007; Supalla, 1982; Zwitserlood, 2003) and the classifiers themselves are expressed by handshapes that classify entities by representing their salient characteristics, predominantly size and shape features (Emmorey, 2002; Supalla, 1982; Zwitserlood, 2003; 2012). Morphological complexity in these forms is argued to be due to several factors such as the use of classifier handshapes (Bernardino, 2006; Brentari et al., 2013; Kantor, 1980; Morgan et al., 2008; Slobin et al., 2003; Supalla, 1982; Tang et al., 2007), the use of a location morpheme by placing hands on sign space (Schick, 1990; Zwitserlood, 2003), and representing the relative locations of Figure and Ground objects simultaneously in a classifier construction (Supalla, 1982; Slobin et al., 2003; Engberg-Pedersen, 2003; Tang et al., 2007; Morgan et al., 2008).

To illustrate, in order to describe a picture of *a pen is to the left of the paper*, signers first introduce the lexical signs for the pen and the paper and later they choose classifier handshapes to indicate the size and shape of these two objects. Specifically, they choose a flat handshape (i.e., flat hand) to represent the flat nature of the paper and an index finger to represent the elongated shape of the pen. Later, they position these handshapes in the signing space in a way analogous to the real space. As depicted in Figure 25c below (see also Figure 8 in **Chapter 2** and Figure 28 in **Chapter 4**), signers position their two handshapes in the signing space placing *the pen* to the left of *the paper* from their own viewpoint. This is typical as TİD signers, like signers of many other sign languages, use their own viewpoint in signing Left-Right spatial relations (Sümer et al., 2016).

Figure 25

An example of a classifier construction by a native signer of TİD to encode the spatial relation between the paper and the pen.



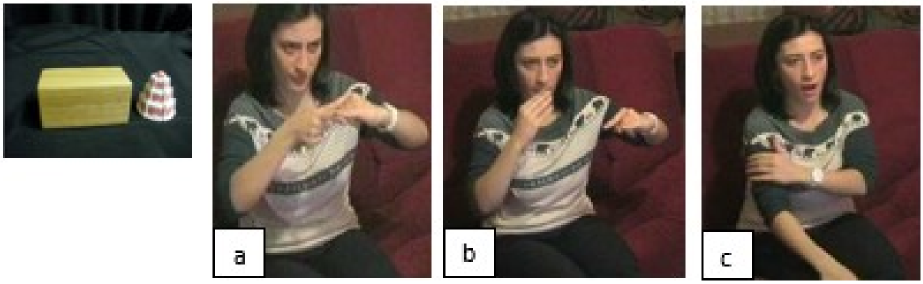
RH:	PAPER	CL(flat)$_{Loc}$	-------- HOLD --------
LH:	-------	PEN	CL(long)$_{Loc}$

"There is a paper. There is a pen. The pen is to the left of the paper."

In addition to classifier constructions, signers can also choose relational lexemes to express spatial relations (Arık, 2013; Perniss et al., 2015a; Sümer, 2015; Sümer et al., 2014). These forms encode the spatial relationship between objects but not the information about the shape of the specific objects themselves. Thus, relational lexemes are semantically less specific and iconic to the size and shape of referents than classifier constructions are since they only exhibit the relationship between any two objects regardless of objects' size and shape. Therefore, as relational lexemes do not require classifier handshapes and locations in space, they are considered to be morphologically simpler than classifier constructions. Although relational lexemes for some spatial relations, such as In-On-Under are signed in the signing space rather than on the body, relational lexemes for Left and Right are found to be body anchored in TİD (see Sümer, 2015; Sümer et al., 2014). The third still of the Figure 26 shows a relational lexeme for RIGHT in TİD to describe a spatial relation between the box and the cake. The third still of the Figure 27 shows a relational lexeme for UNDER in TİD to describe a spatial relation between a cat and a horse.

Figure 26

An example of a relational lexeme for Right by a native signer of TİD to encode the spatial relation between the box and the cake.

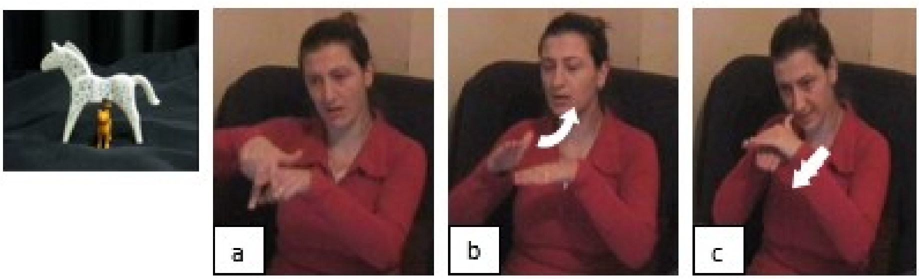


RH:	RECTANGULAR	CAKE	RIGHT
LH:	RECTANGULAR	------- HOLD -------	RIGHT

"There is a rectangular-shaped object. There is a cake. The cake is located to the right of the rectangular-shaped object."

Figure 27

An example of a relational lexeme for Under by a native signer of TİD to encode the spatial relation between the horse and the cat.



RH:	HORSE	CAT	UNDER
LH:	HORSE	CAT	UNDER

"There is a horse. There is a cat. The cat is under the horse."

As depicted in the above examples, producing spatial relations in sign languages always uses the following word order conventions when classifier constructions are produced: Ground object, Figure object, and classifier construction to indicate the location of the Figure object for both viewpoint-dependent and viewpoint-independent relations (see Sümer (2015) for TİD and see also Perniss (2007) for German Sign Language, and Manhardt et al. (2020) for Sign Language of the Netherlands). In TİD, the production of relational lexemes also follows the same word order conventions for both viewpoint-dependent (Figure 26) and viewpoint-independent relations (Figure 27; Sümer, 2015). However, for relational lexemes, the word order may be more variable in different sign languages, unlike for classifier constructions.

3.1.2. Linguistic Development of Locative Relations in Spoken and Sign Languages

The order of learning different types of spatial relations in spoken language acquisition has been argued to be in line with the nonverbal conceptual development about space (Clark, 2004; Johnston, 1985, 1988). We know from previous research that there are some regularities across many spoken languages for children in learning to express spatial relations. Specifically, children first show an understanding of viewpoint-independent spatial concepts, such as containment (i.e., In), support/contact (i.e., On), and occlusion (i.e., Under; see Casasola, 2008; Casasola et al., 2003; Clark, 1973) and learn to map spatial words to these concepts at around age 2. Viewpoint-dependent spatial relations such as Left and Right, however, appear latest and are found to be delayed for hearing children even until 9 years of age (Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; see also Corballis & Beale, 1976). Delays in the acquisition of viewpoint-dependent relations, as opposed to viewpoint-independent relations, are usually attributed to the requirement of development of an understanding of children's own Left-Right (Howard & Templeton, 1966) and then mapping these spatial concepts on other people or objects (Howard & Templeton, 1966; Piaget, 1972). Thus, specifically using these terms to refer to the spatial relation between objects appears late (Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; see also Sümer, 2015 for Turkish).

For sign languages, acquisition of spatial expressions by native signers is found to be delayed in general due to the morphological complexity of such expressions (i.e., due to so-called classifier constructions) and especially for motion event descriptions (e.g., Kantor, 1980; Newport & Meier, 1985; Schick, 1990; Supalla, 1982; Slobin et al., 2003 for American Sign Language; Engberg-Pedersen, 2003 for Danish Sign Language; Tang et al., 2007 for Hong Kong Sign Language). However, a recent study investigating the acquisition of different types of locative relations by native signing compared to speaking children did not find delayed acquisition patterns for viewpoint-dependent relations compared to viewpoint-independent ones for native signing children. It was found that native signing deaf children acquiring TİD encode viewpoint-independent relations (e.g., In-On-Under), as well as the viewpoint-dependent relations (e.g., Left-Right) in adult-like ways already at 5 years of age (Sümer, 2015; Sümer & Özyürek, 2020; Sümer et al., 2014). These are important results as hearing children learning Turkish, who were tested in the same study with the same materials, were found to describe viewpoint-dependent relations in adult-like ways later (at around age 8-9 years) than viewpoint-independent relations, which is similar to what has been found for other spoken languages (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015). A possible explanation for the earlier acquisition of viewpoint-dependent relations by native signing deaf children learning TİD compared to hearing children learning Turkish could be due to the iconic and body-anchored linguistic forms that are used to encode such descriptions in sign languages (see Sümer et al., 2014 for a discussion). Unlike speech, sign language descriptions of space, despite their morphological complexity, incorporate a high similarity between the shape and position of the signers' hands and what they refer to in the real space. In addition to the iconic and body-anchored linguistic forms used in sign language expressions of space, one-to-one mapping between the exact spatial relation and sign language expression of space might have eased the production of viewpoint-dependent forms for native signing children (see Martin & Sera, 2006; Morgan et al., 2008). Furthermore, the semantic simplicity of locative relations compared to motion events might also account for their early acquisition (see Talmy, 1985, 2003). The earlier acquisition of spatial relations in sign in comparison to speech might indicate how linguistic affordances of the language have the potential to interact with cognitive development to shape spatial language development (e.g., Bowerman, 1996a, 1996b).

Sümer (2015) found that native signing children use both of these forms (i.e., classifier constructions and relational lexemes) that allow for iconic and body-anchored mappings to describe viewpoint-dependent and viewpoint-independent relations in adult-like ways around 5 years of age. However, it is not known whether late signing children would also benefit from iconicity of these locative expressions and learn viewpoint-dependent relations as early as viewpoint-independent ones 2 years after exposure. Alternatively, late exposure might affect the development of viewpoint-dependent relations more than viewpoint-independent ones as the former is known to be acquired later by hearing children possibly driven by their conceptual complexity. Finally, the effects of late exposure might depend both on the complexity of the spatial domain and the type of linguistic forms (i.e., iconicity, morphological complexity).

Before we move onto the present study, we will review previous studies investigating the effects of late sign language exposure on linguistic abilities in general and the production of spatial language more specifically.

3.1.3. Effects of Late Exposure on Sign Language Development

Studies on the effects of late sign language exposure on the general linguistic abilities (see Mayberry & Kluender, 2018 for a review) have investigated the influence of both the age of exposure as well as years of exposure on patterns of sign language acquisition focusing mostly on adolescent and adult late signers. Longitudinal studies investigating the developmental trajectories of sign language acquisition of deaf adolescent late signers compared to younger native signing children (groups matched in terms of the years of exposure to language) found similar acquisition patterns in the development of mean length of utterance and sentence complexity (see Ramirez et al., 2013). Additionally, a study by Cheng and Mayberry (2019) investigating the developmental trajectories of 3 deaf adolescent late signers (data collected longitudinally from 12 months to 6 years of exposure to American Sign Language) show that deaf adolescent signers go through stages similar to the literature reported for native signing deaf children in the development of canonical word order. Similarly, late signing children who are exposed to a sign language around age 6 showed comparable performance in all of the language measures (e.g., Mean Length of Utterance) to native signing deaf children who have equal years of exposure to a sign language (Berk & Lillo-Martin, 2012). Even though these studies show similar patterns of development after late exposure, studies conducted with adult signers who were exposed to a sign language in childhood show that late exposure has enduring effects in adulthood and late signing adults have lower accuracy in the grammatical judgment of sentences in American Sign Language (Boudreault & Mayberry, 2006) and decrease in recall performance of complex sentences in American Sign Language (Mayberry, 1993) as a function of the age of exposure to language. It should be noted that in the above studies developmental patterns in late signing children have not been compared directly to age-matched native signing children but only to those with equal years of language exposure.

To our knowledge, an even smaller number of studies have been conducted on the effect of late exposure on the production of spatial language. These few studies have focused mostly on the domain of motion event descriptions that are semantically and morphologically more complex than locative spatial relations (Talmy, 1985, 2003). They have investigated the acquisition of motion event expressions either by late signing adults (Newport, 1988, 1990; Schick, 1990) and adolescents who have been exposed to a sign language first time (Morford, 2003) or homesigning children around 5 years of age without any exposure to a sign language (Gentner et al., 2013).

Newport (1988, 1990) found that early exposure to a sign language is crucial especially for mastering morphologically complex verbs of motion and that late exposure has long-lasting effects on their mastery even in adulthood. She studied production patterns of late signing adults who were exposed to a sign language at ages between 4-6 as well as after age 12 at school from their deaf peers by comparing them to native signing adults in descriptions of motion events. Results show a linear decline in their mastery as a function of the age of acquisition to language. This study, however, was restricted only to late signing adults and information about late signing children after they have been exposed to a sign language is missing.

Morford (2003) investigated the language acquisition patterns of 2 adolescent late signers who are exposed to American Sign Language after age 12;1 and 13;7. These children are tested after 2, 8, 14, 20, 31 months of exposure to American Sign Language on describing motion events in the frog story that are typically expressed by morphologically complex verbs of motion. Morford (2003) found different patterns of acquisition between the two signers in using these forms. One of her participants started using monomorphemic signs (e.g., to encode the frog climbing out of the jar, she used the sign OUT) in the first session and gradually replaced monomorphemic signs with verbs of motion with classifier constructions in the subsequent sessions. However, the other participant showed the acquisition trajectory resembling first language acquisition patterns of native signers. He first expressed verbs of motion at the second testing session although with errors (i.e., handshape is correct but the location is wrong) and gradually improved his use of these forms and never used monomorphemic signs in any of the testing sessions. Results of this study show that although these participants showed variability in acquiring verbs of motion to describe motion events, both of them increased the frequency and accuracy of their use of these forms by 31 months of exposure to American Sign Language. Thus, linguistic structures to encode space require some time for late signing adolescents to acquire.

Finally, there is also research about communicative strategies used by deaf children (ages 5-6) before they had any exposure to a conventional sign language (i.e., homesigners; Gentner et al., 2013). Deaf children were shown video clips that are likely to elicit spatial relations between Figure and Ground objects (e.g., a box moves on top of a school bus). Results showed that deaf children showed no evidence for language-like expressions in their gestures to convey spatial relations while describing motion event video clips. Therefore, language input seems to be crucial for children to express spatial relations in language-like ways and cannot evolve through gestural interactions with caregivers without any conventional sign language input and despite the iconic features of these expressions.

However, several issues regarding the role of late language exposure on the language development of space remain to be asked. First of all, previous studies do not give a comprehensive picture as to how late signing children develop linguistic strategies for communicating about space after being exposed to a sign language. Morford (2003) conducted her research on 2 adolescent late signers who showed different profiles for the development of spatial language and Newport (1988, 1990) conducted her studies with late signing adults only. Moreover, Gentner et al. (2013) looked at deaf children before they were exposed to a sign language but did not follow up on their development after exposure to language. That is, after starting the school for the deaf.

Without focusing on late signing children shortly after exposure to a sign language and comparing them to their native signing peers and late signing adults, we cannot fully comprehend the role of cognition and linguistic development in late sign language exposure of spatial expressions. This information is crucial to see as to what extent the spatial language development is shaped by early versus late language exposure. Furthermore, most research has been in the domain of motion events that have complex morphological structures and semantics (Talmy, 1985, 2003) and not much is known on the development of simpler locative relations.

Hence, in the present study, we investigate the developmental patterns of locative relations in late signing children after 2 years of exposure compared to age-matched native signing children as well as late signing adults compared to their native signing counterparts. It is possible that locative relations are more resistant to late input for adults and/or children due to their semantic simplicity unlike those shown for motion event expressions. More specifically, we are interested in whether viewpoint-dependent and viewpoint-independent relations are equally sensitive to late language input in children and adults, due to their iconic affordances as found in Sümer (2015) for native signing children or whether viewpoint-dependent relations are harder to learn in late language exposure situations as they are learned at later stages of cognitive development. Finally, we investigate if the morphological complexity of the linguistic forms to encode spatial relations is differentially affected by late sign language exposure.

3.2. The present study

Our overall aim in this study is to get an understanding of the effect of late language exposure on the development of spatial language by children and adults in the domain of locative spatial relations. In order to accomplish this, we focused on descriptions of two types of relations: viewpoint-dependent and viewpoint-independent. We collected data from late signing adults and children (that is after 2 years of sign language exposure) and compared them to native signing adults and children collected in Sümer (2015). We also used the same materials as in Sümer (2015).

The rationale for choosing 2 years of exposure to a sign language by late signing children is twofold: First, we wanted to allow late signing children to get enough exposure to observe a developmental pattern. Also, we wanted to make sure that children are cognitively mature enough to learn to express viewpoint-dependent relations as they are known to be learned late by hearing children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; see also Corballis & Beale, 1970; Hermer-Vazquez et al., 2001).

3.2.1. Predictions

First, we investigate whether late signing children and adults lag behind their native signing peers in expressing locative relations in general as found for motion event expressions (see Morford, 2003; Newport, 1988, 1990) or whether such forms are more resilient to the late exposure due to their relative simplicity. The latter case would indicate that linguistic forms can easily map onto independently developing cognitive representations of spatial relations. However, if linguistic factors play an important role in shaping cognitive development of space late signing children and adults will lag behind their counterparts.

Secondly, we are interested in seeing whether late sign language acquisition impacts viewpoint-dependent and viewpoint-independent relations differently. It is possible that even after only 2 years of exposure, late signing children *do* acquire descriptions of both forms of locative spatial relations in adult-like ways as found for native signing children by Sümer (2015) due to their iconic and body-anchored properties. However, it is also possible that viewpoint-dependent relations might be delayed compared to viewpoint-independent relations as they are learned later by hearing children and thus effects of late language exposure might be more salient for viewpoint-dependent relations than viewpoint-independent relations. This would indicate the order of conceptual development of space playing a role in spatial language development also in late language exposure (Benton, 1959; Clark, 1973; Corballis & Beale, 1976; Harris, 1972; Johnston & Slobin, 1979; Piaget, 1972; Sümer, 2015; Sümer et al., 2014). If the early effects carry on to the final attainment of language development, we could also see different patterns for viewpoint-dependent and viewpoint-independent relations in descriptions of late signing adults, the former being more susceptible to late input than the latter.

Finally, we are interested in seeing whether the morphological complexity of the linguistic forms to encode spatial relations would be differentially affected by the late sign language exposure. Morphologically complex forms such as classifier constructions might be more susceptible to the effect of late language exposure compared to simpler forms such as relational lexemes. If morphological complexity is sensitive to late language exposure (see Newport, 1988, 1990), we might expect classifier constructions to be more delayed by late signing children and adults compared to morphologically simpler forms (e.g., pointing) and perhaps morphological complexity of the forms might even interact with the type of locative relation expressed.

3.3. Methods

3.3.1. Participants

Forty-four deaf signers of TİD residing in Istanbul, Turkey were recruited for this study. Participants reported in this study consisted of four groups: 12 late signing deaf adults (Mean Age = 38;2; Age Range = 28;8-49), 9 late signing deaf children (Mean Age = 8;5; Age Range = 7;9-9;9, additional 2 children were excluded from the analyses after the coding due to failing to follow the instructions), 10 native signing deaf adults (Mean Age = 31;4; Age Range = 18;5-45;10), and 11 native signing deaf children (Mean Age = 8;5; Age Range = 7;2-9;11). All data from native deaf signers, except one child, were collected as part of a bigger project conducted between 2010 and 2015 and reported in Sümer (2015). All native signers have had exposure to a sign language from birth. All late signing adults and children started to learn TİD at primary school for the deaf around age 6. At the time of data collection, late signing children had around 2 years of sign language exposure in their school environment. Adult participants reported in this study have reported themselves to be profoundly deaf and unable to understand spoken Turkish. For child participants, this information was obtained from their parents and/or teachers.

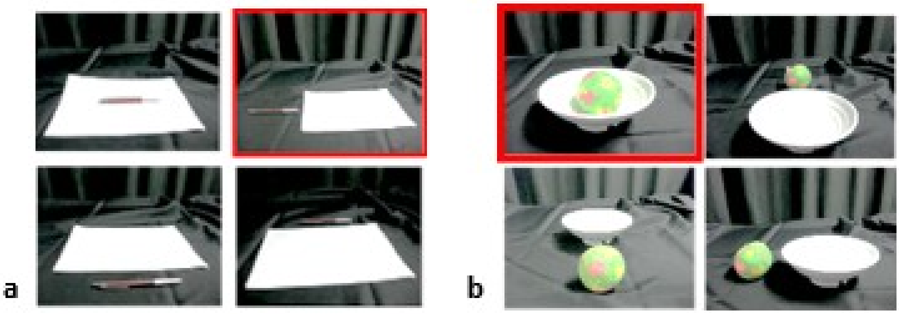
Unlike in countries with general newborn hearing screening and robust early intervention, in Turkey deaf children typically get exposed to a sign language when they start deaf school around 6 years of age (İlkbaşaran, 2015). In deaf schools in Turkey, deaf children do not learn sign language as part of their curriculum as all of these schools employ oral education. These children receive all of their sign language input by interacting with their late or native signing peers during recess.

3.3.2. Stimuli

Stimuli consisted of 36 displays with a set of 4 pictures. These displays have been adapted by Sümer (2015) from displays originally developed by Dr. Jennie Pyers. Each picture showed Figure (small object; e.g., pen) and Ground (large object; e.g., paper) objects placed in various spatial configurations (e.g., *Pen is to the left of the paper*, *Apple is to the right of the box*, *Ball is in the bowl*, *Toothbrush is on the cup*, *Cup is under the table*, *Cake is in front of the box*, *Cup is behind the box*). Each display had one target picture, which was marked with a red outer frame, to be described to a confederate addressee sitting across the table. The remaining pictures in each display either contained three other pictures with the same Figure and Ground objects in different spatial configurations or two other pictures with the same Figure and Ground objects in different spatial configurations and an additional picture with different Figure and Ground objects. Some of the objects (e.g., ladybug, pig, motorcycle, giraffe) used in the dataset were not familiar to participants and thus participants failed to identify and name them. Thus, first, we took them out of further analyses. Later, we created and analyzed a remaining subset of 15 displays that contained viewpoint-independent relations for containment (In), support/contact (On) and occlusion (Under), as well as displays in which the target picture required signers to take a viewpoint such as Left-Right. These included quasi-randomly selected 3 displays per spatial relation type for which participants were able to name all of the objects in target pictures. While selecting the final displays to be analyzed, we also tried to reflect the general qualities of the overall dataset mentioned above. Half of the displays included four pictures in the one display with the same Figure and Ground objects (n = 8) and a half included three pictures with the same Figure and Ground objects and a remaining picture with different Figure and Ground objects (n = 7). See Figure 28 for example displays and Appendix for all displays. Please note that these stimuli are different than that of the remaining chapters.

Figure 28

Example of displays with target picture with (a) viewpoint-dependent spatial relation (i.e., Left) and (b) viewpoint-independent spatial relation (i.e., In).

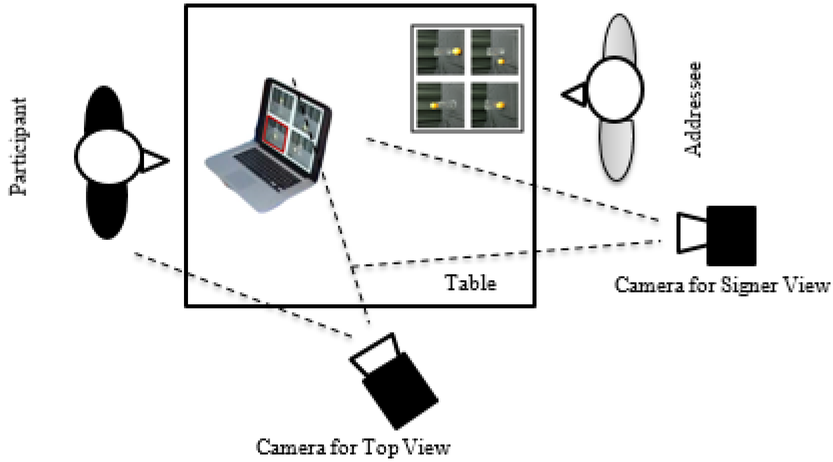


3.3.3. Procedure

Participants were seated across a confederate addressee, who was a deaf native TİD signing adult. Due to the small size of the deaf community in Istanbul, the addressee was familiar to some of the participants in a few cases. Stimuli were presented through a 15-inch MacBook Pro computer. The computer screen was only visible to the participants. All instructions were given in TİD by the addressee herself. Participants were asked to describe the target pictures to the addressee in a fixed order. In order not to prime participants in certain linguistic strategies, no examples from TİD was given to the participants. In order to create a communicative nature for the task, the addressee was given a booklet containing the same displays without a red frame and was asked to find and point at the picture that the participant described on the booklet. This booklet was visible to the participant and thus the participant saw which picture that the addressee had pointed based on the description. Addressee did not give any feedback on whether or not the descriptions were correct. In cases where the participants did not express the spatial relations, the addressee only asked for the location of the Figure object using the lexical sign of WHERE in TİD and the lexical sign of the Figure object in the target picture. Thus, addressee feedback did not provide any linguistic strategies to locate the Figure object in relation to the Ground object. At the end of the study, adult participants received a small monetary compensation and child participants received a gender-neutral color pencil kit. Figure 29 illustrates the experimental setup.

Figure 29

Illustration of the experimental set up.



3.3.4. Annotation and Coding: Spatial Descriptions

All descriptions were annotated and coded for Target Pictures using ELAN (Version 4.2 for Native Signers and Version 4.9.3 for Late Signers), a free annotation tool (http://tla.mpi.nl/tools/tla-tools/elan/) for multimedia resources developed by the Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Wittenburg et al., 2006). Data of the late signers were annotated by a hearing L2 signer of TİD and later coded another hearing L2 signer of TİD. The data from the native signers were annotated by a hearing L2 signer of TİD and coded by another hearing L2 signer of TİD. Later, coding was checked by a trained deaf native signer of TİD. We did not have a reliability coding as we only included the linguistic forms that were unambiguously approved by this native signer in the final dataset.

First of all, we removed all "no attempt" trials and thus coding is based on trials that participants attempted to describe the Target Picture. Coding is done in two steps. First, we coded for the presence of expression of the spatial relation between the objects per description. Secondly, we coded the types of linguistic forms used to localize the Figure object in relation to the Ground objects for each description. There were some descriptions with incorrect spatial relation between the Figure and Ground objects (e.g., describing that the pen is to the front of the paper, although the target picture showing that the pen is to the left of the paper). Moreover, there were also descriptions with missing spatial relation (i.e., descriptions containing only labeling of the presence of Figure and Ground objects but not the spatial relation of the Figure object in relation to the Ground object). We coded descriptions with incorrect and missing spatial relation as having No Spatial Encoding and we did not further code for the linguistic form used in these descriptions.

3.3.4.1. Linguistic Forms

Coding of the linguistic forms used to localize the Figure object in relation to the Ground object showed that our participants used five forms that we grouped into three categories: a) classifier constructions, b) relational lexemes, and c) Other forms (pointing, tracing of the object shapes in the signing space, and lexical verb placements).

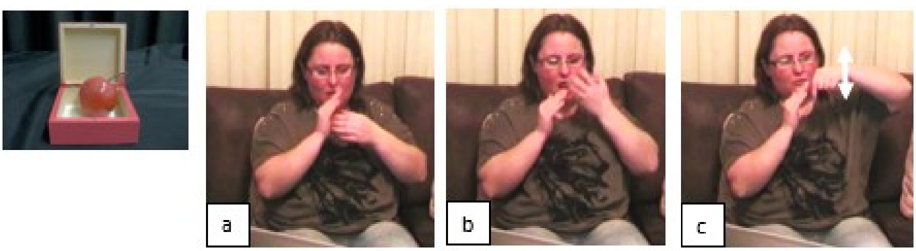
Use of classifier constructions (see 3rd still of the Figure 25 above; see also Figures 2 and 3 from **Chapter 1**, Figure 13 from **Chapter 2**, and Figure 36 from **Chapter 4**) is one of the most common linguistic forms to localize Figure object in relation to the Ground object in general for sign languages (e.g., Emmorey, 2002) and also for TİD (see Arık, 2013; Sümer, 2015; Sümer et al., 2014). The use of classifier constructions is semantically the most specific way of encoding a relationship between two entities since they allow for encoding the information about the entities through the handshape classifications of the objects (see Manhardt et al., 2020; Perniss, et al., 2015a). Within our data, we encountered two types of classifier constructions (i.e., Entity and Handling; Zwitserlood, 2012). For the analyses, we collapsed these two types into one group. Moreover, within all three categories (classifier constructions, relational lexemes and Other forms), classifier constructions are the most common form to differ in terms of handshape choices and are morphologically the most complex. In order to ensure that late and native signers are comparable in their use of classifier constructions, we checked all the classifier handshapes used by late signers to see if native signers also used the same handshapes as a classifier for the same object. As a result, none of the handshapes produced by late signers was found to be idiosyncratic and all were present in the handshape repertoire of the native signers for the exact same object. We checked this at the object level and we did not have a detailed handshape coding (see Janke & Marshall, 2017 for a detailed coding scheme).

The second common form was using relational lexemes. This is a form used in TİD as an alternative to or in combination with classifier constructions and is morphologically simpler than classifier constructions (Arık, 2013; Sümer, 2015; Sümer et al., 2014; see 3rd stills of the Figure 26 and Figure 27 above; see also Figure 19 from **Chapter 2**). It also differs from classifier constructions in that the signs are not localized in sign space but they more generally show the left or right side of the body (body-anchored, see Figure 26 above).

Finally, we grouped a few other types of forms into a third category. These included a) pointing to the location of the Figure object in the signing space (Figure 30 below; see also Figure 21 from **Chapter 2**), b) tracing the shape of the Figure object in the signing space (Figure 31 below; see also Figure 20 from **Chapter 2**) and c) placing a lexical verb in sign space (see Newport, 1988 for the discussion of single-morpheme signs) to represent the Figure object in the signing space (Figure 32 below). We labeled them as "Other forms". We grouped them because none of them was frequent enough to make a unified single category. Note that Other forms, like relational lexemes, are morphologically less complex than classifier constructions as these forms do not incorporate the size and shape information of the entities in describing spatial relations.

Figure 30

An example of pointing with index finder by a native signer of TİD to encode the spatial relation between the box and the apple.

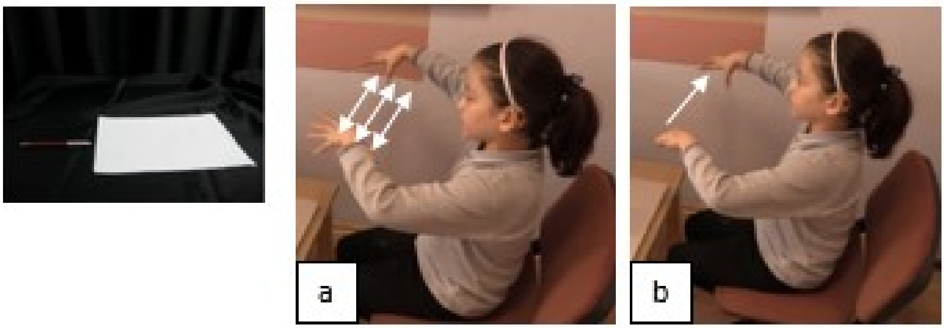


RH:	BOX	CL(Box)$_{Loc}$	----HOLD----
LH:	BOX	APPLE	Pointing(Apple)$_{Loc}$

"There is a box. There is an apple. Apple is here."

Figure 31

An example of tracing by a native signer of TİD to encode the spatial relation between the paper and the pencil.

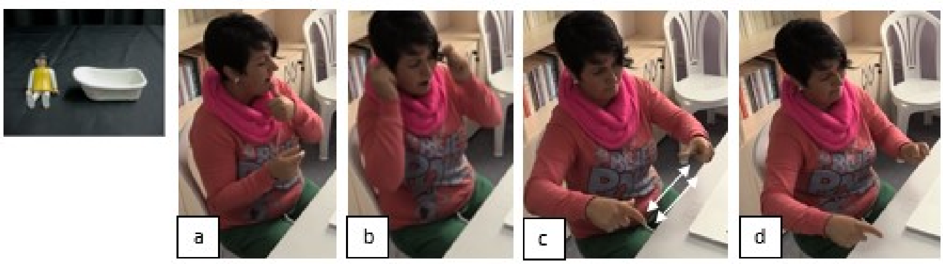


RH:	Tracing(Paper)$_{Loc}$	----HOLD----
LH:	Tracing(Paper)$_{Loc}$	Tracing(Pen)$_{Loc}$

"There is a paper. Pen is located left to the paper."

Figure 32

An example of lexical verb placement (TO SIT) by a late signer of TİD to encode the spatial relation between the bathtub and the girl.



LH:	GIRL	BATH	Tracing(Bath)$_{Loc}$	LV (to sit)
RH:	-----	BATH	Tracing(Bath)$_{Loc}$	----HOLD----

"There is a girl. There is a bath. The girl is located to the left of the bath."

3.4. Results

Data presented in this section were analyzed using generalized binomial linear-mixed-effects modeling (*glmer*) with random intercepts for Subjects and Items. All models were fit with the *lme4* package (version 1.1.17; Bates et al., 2014) in R (R Core Team, 2018) with the optimizer *bobyqa* (Powell, 2009). This mixed-effects approach allowed us to take into account the random variability due to having different participants and different items. For completeness, we chose the most inclusive model over the most parsimonious model and did not remove the non-significant effects for the models presented in this section.

3.4.1. The Frequency and the Type of Spatial Encoding

First, we investigated the frequency of encoding the spatial relation of the Figure object to the Ground object by Language Status and Age Group for all descriptions produced by participants. Table 2 presents the proportion of encoding the spatial relation of the Figure object to the Ground object across different age groups and language statuses. We used a glmer model to test the fixed effects of Language Status (Late, Native) and Age Group (Children, Adults) on binary values for the presence of the spatial encoding in descriptions (1 = Spatial Encoding, 0 = No Spatial Encoding) at the item level. Subject and Item were entered as random intercepts. Fixed effects (i.e., Language Status, Age Group) were analyzed with centered contrasts (−0.5, 0.5). Table 3 presents fixed estimates from glmer model for encoding the spatial relation. The model revealed a main effect of Age Group. Adults generated more spatial encodings compared to children regardless of language status. No other effects or interactions were significant, indicating that both native and late signers generated equal amounts of spatial encodings.

Table 2

Mean proportions (SD) of encoding a spatial relation.

	Native	Late
Adults	0.98 (0.14)	0.98 (0.15)
Children	0.94 (0.24)	0.85 (0.36)

Table 3

Fixed effect estimates from the glmer model for encoding the spatial relation between Figure object in relation to the Ground object.

Fixed Effect				
	β	*SE*	*z*	*p value*
(Intercept)	3.559	0.404	8.817	<0.001***
$\text{Language}_{\text{Native vs Late}}$	0.587	0.568	1.033	0.302
$\text{Age}_{\text{Adults vs Children}}$	1.735	0.577	3.004	0.003*
$\text{Language}_{\text{Native vs Late}}$:$\text{Age}_{\text{Adults vs Children}}$	-1.124	1.145	-0.981	0.327

Significance codes: ***<0.001, **<0.01, *<0.05

Formula in *R*: Spatial_Encoding ~ Language * Age + (1|Subject) + (1|Item)

All subsequent analyses were conducted on descriptions in which spatial relation encoding was present. As a next step, we analyzed for factors (i.e., Language Status, Age Group, Viewpoint) that contribute to the choice of the linguistic forms (i.e., classifier constructions, relational lexemes, and Other forms) used to encode the location of the Figure object in relation to the Ground object. In the sections below, models for classifier constructions, relational lexemes, and Other forms are discussed.

As in some of the descriptions, participants used more than one linguistic form to describe the spatial relation in the target picture (e.g., one description could include both classifier constructions and relational lexemes). These cases were counted for the presence of the classifier constructions category as well as for the relational lexemes category (See Table 4). Consequently, the results presented in this part include all of the strategies for a single description and thus allow us to investigate each linguistic form with separate models.

Table 4

Mean proportions (SD) of types of linguistic forms across age group, language status, and viewpoint.

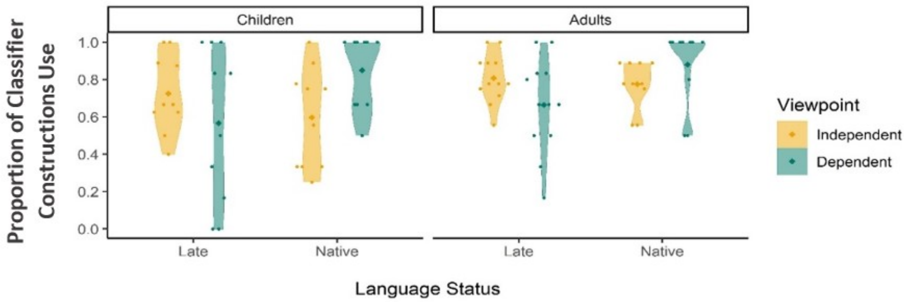
	Viewpoint-Independent		Viewpoint-Dependent	
	Late	Native	Late	Native
Classifier Constructions				
Children	0.70 (0.46)	0.53 (0.50)	0.54 (0.50)	0.86 (0.36)
Adults	0.74 (0.44)	0.71 (0.46)	0.65 (0.50)	0.88 (0.33)
Relational Lexemes				
Children	0.14 (0.35)	0.33 (0.47)	0.06 (0.23)	0.18 (0.39)
Adults	0.29 (0.45)	0.21 (0.41)	0.28 (0.45)	0.28 (0.45)
Other Forms				
Children	0.19 (0.39)	0.12 (0.33)	0.52 (0.50)	0.06 (0.23)
Adults	0.05 (0.21)	0.10 (0.30)	0.27 (0.45)	0.04 (0.19)

3.4.2. Classifier Constructions

First, we investigated the frequency of classifier constructions use by each Language Status, Age Group, and Viewpoint. Table 4 and Figure 33 show the proportion of classifier constructions use across Language Status, Age Group, and Viewpoint. We used a glmer model to test the fixed effects of Language Status (Late, Native), Age Group (Children, Adults) and Viewpoint (Viewpoint-independent, Viewpoint-dependent) on binary values for the presence of spatial description by classifier constructions (0 = No, 1 = Yes) at the item level. All fixed effects (i.e., Language Status, Age Group, and Viewpoint) were analyzed with centered contrasts (−0.5, 0.5). Subject and Item were entered as random intercepts.

Figure 33

Proportion of classifier constructions use as a function of age group, language status, and viewpoint.



Notes. Dots represent the average data for each participant. Rectangle represents the mean. The width of the violins represents the density of the data distribution. Length of the violins depict the range of the data points.

Table 5 presents the fixed effect estimates from glmer on descriptions with classifier constructions. The model revealed an interaction between Language Status and Viewpoint. When describing viewpoint-dependent relations late signers produced fewer classifier constructions (0.60) compared to native signers (0.87). However, late (0.73) and native (0.62) signers produced classifier constructions in statistically similar frequencies when describing viewpoint-independent relations (see Figure 33). No other effects and interactions were significant indicating that choice of classifier constructions as a linguistic form to describe spatial relations between objects did not vary across Age Groups.

3.4.3. Relational Lexemes

Next, we investigated the frequency of relational lexemes use by each Language Status, Age Group, and Viewpoint. Table 4 and Figure 34 present the proportion of relational lexemes used across each Language Status, Age Group, and Viewpoint. We used a glmer model to test the fixed effects of Language Status (Late, Native), Age Group (Children, Adults) and Viewpoint (Viewpoint-independent, Viewpoint-dependent) on binary values for the presence of spatial description by relational lexemes (0 = No, 1 = Yes) at the item level. All fixed effects (i.e., Language Status, Age Group, and Viewpoint) were analyzed with centered contrasts (−0.5, 0.5). Subject and Item were entered as random intercepts.

Table 5

Fixed effect estimates from the glmer model for frequency of classifier constructions use.

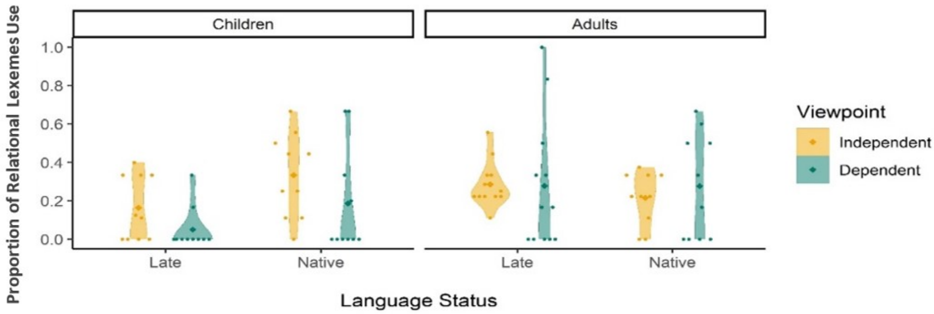
Fixed Effect				
	β	*SE*	*z*	*p value*
(Intercept)	1.556	0.393	3.96	<0.001***
$\text{Age}_{\text{Adults vs Children}}$	0.628	0.443	1.416	0.157
$\text{Language}_{\text{Native vs Late}}$	0.636	0.443	1.434	0.152
$\text{Viewpoint}_{\text{Dependent vs Independent}}$	-0.139	0.682	-0.204	0.839
$\text{Age}_{\text{Adults vs Children}}$:$\text{Language}_{\text{Native vs Late}}$	-0.070	0.885	-0.079	0.937
$\text{Age}_{\text{Adults vs Children}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	-0.494	0.483	-1.022	0.307
$\text{Language}_{\text{Native vs Late}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	2.393	0.490	4.885	<0.001***
$\text{Age}_{\text{Adults vs Children}}$:$\text{Language}_{\text{Native vs Late}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	-0.802	0.961	-0.834	0.404

Significance codes: ***<0.001, **<0.01, *<0.05

Formula in *R*: ClassifierConstructions ~ Age * Language * Viewpoint + (1|Subject) + (1|Item)

Figure 34

Proportion of relational lexemes use as a function of age group, language status, and viewpoint.



Notes. Dots represent the average data for each participant. Rectangle represents the mean. The width of the violins represents the density of the data distribution. Length of the violins depict the range of the data points.

Table 6 presents the fixed effect estimates from *glmer* on relational lexemes use. The model revealed a main effect of Age Group. Adults (0.26) used more relational lexemes compared to children (0.19). The model also revealed an interaction between Age Group and Viewpoint. That is, averaged across Language Status, while describing viewpoint-dependent relations, Adults (0.28) used more relational lexemes than children (0.12), whereas, while describing viewpoint-independent relations Adults (0.25) and Children (0.24) used relational lexemes in statistically similar frequencies. Moreover, the model also revealed a significant interaction between Age Group and Language Status. Averaged across Viewpoint, late signing children used relational lexemes less than all other groups. That is, late signing children used relational lexemes (0.11) less than native signing children (0.27) and native signing adults use relational lexemes in statistically similar frequencies (0.24) to late signing adults (0.28). No other effects and interactions were significant.

Table 6

Fixed effect estimates from the glmer model for frequency of relational lexemes use.

Fixed Effect	*β*	*SE*	*z*	*p value*
(Intercept)	-1.765	0.366	-4.823	<0.001***
Age$_{\text{Adults vs Children}}$	0.785	0.372	2.111	0.035*
Language$_{\text{Native vs Late}}$	0.536	0.371	1.444	0.149
Viewpoint$_{\text{Dependent vs Independent}}$	-0.084	0.671	-0.125	0.901
Age$_{\text{Adults vs Children}}$:Language$_{\text{Native vs Late}}$	-1.612	0.744	-2.167	0.030*
Age$_{\text{Adults vs Children}}$:Viewpoint$_{\text{Dependent vs Independent}}$	1.136	0.514	2.212	0.027*
Language$_{\text{Native vs Late}}$:Viewpoint$_{\text{Dependent vs Independent}}$	0.171	0.513	0.333	0.739
Age$_{\text{Adults vs Children}}$:Language$_{\text{Native vs Late}}$:Viewpoint$_{\text{Dependent vs Independent}}$	0.618	1.030	0.600	0.549

Significance codes: ***<0.001, **<0.01, *<0.05

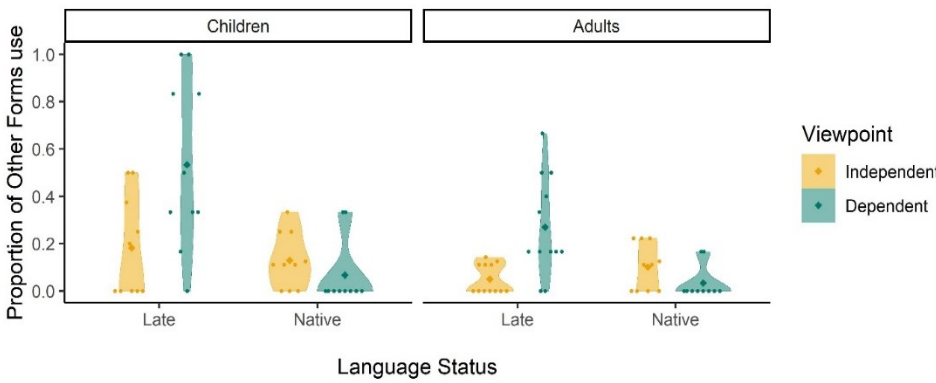
Formula in *R*: RelationalLexeme ~ Age * Language * Viewpoint + (1|Subject) + (1|Item)

3.4.4. Other Forms

Finally, we investigated the frequency of Other forms by each Language Status, Age Group, and Viewpoint. Table 4 and Figure 35 presents the proportion of Other forms across each Language Status, Age Group, and Viewpoint. See also Tables 7 and 8 for the distribution of types of Other forms for each Language Status, Age Group and Viewpoint. We used a glmer model to test the fixed effects of Language Status (Late, Native), Age Group (Children, Adults) and Viewpoint (Viewpoint-independent, Viewpoint-dependent) on binary values for the presence of spatial description by Other forms (0 = No, 1 = Yes) at the item level. All fixed effects (i.e., Language Status, Age Group and Viewpoint) were analyzed with centered contrasts (−0.5, 0.5). Subject and Item were entered as random intercepts.

Figure 35

Proportion of Other Forms use as a function of age group, language status and viewpoint.



Notes. Dots represent the average data for each participant. Rectangle represents the mean. The width of the violins represents the density of the data distribution. Length of the violins depict the range of the data points.

Table 9 presents the fixed effect estimates from glmer on descriptions with Other forms. The model revealed a main effect of Age Group. Children (0.21) used Other forms more than adults (0.11). Moreover, the model also revealed a main effect of Language Status in which late signers (0.22) used Other forms more than native signers (0.09). Additionally, the model revealed a significant interaction between Language Status and Viewpoint. That is, averaged across age group, when describing viewpoint-dependent relations late signers (0.38) produced Other forms more than native signers (0.05), when describing viewpoint-independent relations, however, late (0.11) and native (0.11) signers used Other forms in statictically similar frequencies.

Table 7

Mean proportions of different Forms out of all Other forms used in the descriptions of viewpoint-independent relations.

	Pointing	Tracing	Lexical Verb Placement
Native Signers			
Adults	100	-	-
Children	0.83	-	0.17
Late Signers			
Adults	0.80	0.2	-
Children	0.69	0.31	-

Table 8

Mean proportions of different Forms out of all Other forms used in the descriptions of viewpoint-dependent relations.

	Pointing	Tracing	Lexical Verb Placement
Native Signers			
Adults	0.50	-	0.50
Children	0.20	0.60	0.20
Late Signers			
Adults	0.78	-	0.22
Children	0.79	0.07	0.14

Table 9

Fixed effect estimates from the glmer model for frequency of Other forms.

Fixed Effect				
	β	*SE*	*z*	*p value*
(Intercept)	-2.261	0.295	-7.661	<0.001***
$\text{Age}_{\text{Adults vs Children}}$	-0.913	0.405	-2.252	0.024*
$\text{Language}_{\text{Native vs Late}}$	-1.389	0.408	-3.407	<0.001***
$\text{Viewpoint}_{\text{Dependent vs Independent}}$	0.606	0.509	1.191	0.234
$\text{Age}_{\text{Adults vs Children}}$:$\text{Language}_{\text{Native vs Late}}$	1.229	0.812	1.513	0.130
$\text{Age}_{\text{Adults vs Children}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	0.142	0.651	0.218	0.828
$\text{Language}_{\text{Native vs Late}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	-2.983	0.655	-4.555	<0.001***
$\text{Age}_{\text{Adults vs Children}}$:$\text{Language}_{\text{Native vs Late}}$:$\text{Viewpoint}_{\text{Dependent vs Independent}}$	-0.747	1.300	-0.575	0.566

Significance codes: ***<0.001, **<0.01, *<0.05

Formula in *R*: Other forms ~ Age * Language * Viewpoint + (1|Subject) + (1|Item)

3.4.5. Summary of Results

In summary, late sign language acquisition did not affect the amount of spatial encoding. Thus, late signing children after 2 years of exposure to a sign language seem to be able to express spatial relations as frequently as their native signing peers. However, factors such as Language Status, Viewpoint, and Age Group differentially affect the choice of linguistic forms used to describe spatial relations between two objects.

The frequency of classifier constructions and Other forms were modulated by late sign language exposure and the viewpoint of the items to be described. Results showed that both child and adult late signers produced classifier constructions less frequently in describing viewpoint-dependent spatial relations compared to native signers. This pattern, however, is opposite for Other forms, which are morphologically simpler. When describing viewpoint-dependent relations both child and adult late signers used them more frequently than native signers. When describing viewpoint-independent relations, these effects were not present for using either classifier constructions or Other forms use. Both child and adult late signers produced classifier constructions and Other forms as frequently as their native signing peers did in describing viewpoint-independent relations. Moreover, children used Other forms more than adults and late signers used Other forms more than native signers as found in main effects regardless of the viewpoint.

The frequency of relational lexemes, which is also a morphologically simpler form, is also influenced in general by Age Group where adults used more relational lexemes compared to children. The frequency of relational lexemes use is further modulated by Age Group and Viewpoint on the one hand and Age Group and Language on the other. These interactions indicate first of all that for viewpoint-dependent relations, children used relational lexemes less frequently than adults while for viewpoint-independent relations children and adults used relational lexemes in statistically similar frequencies. Secondly, averaged across viewpoint of the items, late signing children used relational lexemes less frequently compared to their native signing peers. Late signing adults, however, became native-like in the frequency of relational lexemes use.

3.5. Discussion

In this study, we investigated the effects of late sign language exposure on expressions of spatial language by deaf adults and children acquiring TİD. We studied age-matched native and late signing adults and children in the same study to understand the effect of late sign language exposure on the development of spatial language use. Extending the knowledge in the literature, first, we investigated the impact of late exposure on descriptions of locative spatial relations to see whether the effects found for motion event descriptions in previous research extend to simpler forms of spatial language. Second, we base our investigation on two different types of spatial relations, namely viewpoint-dependent, and viewpoint-independent relations in order to capture the possible effect of cognitive development in learning to express spatial relations interacting with late sign language exposure. Moreover, we investigated whether the morphological complexity of the linguistic form to encode locative spatial relations is differentially affected by late sign language exposure and whether this is modulated by the type of spatial relation to be described.

First of all, our study showed that late sign language exposure does not affect the number of spatial encodings of locative relations by late signers compared to native signers. This is a rather novel finding, as we know from previous research on Turkish deaf homesigning children that their gestural descriptions do not convey spatial relations prior to a sign language exposure (Gentner et al., 2013). Thus, within 2 years of exposure to a sign language, late signing children can already express equal amounts of spatial encodings compared to their native signing peers in describing spatial relations. Thus, the conceptualization of spatial relations seems to develop relatively independently; that is without language exposure in the first 6 years of life. When spatial language is available in the input, it can easily map onto these concepts. Furthermore, results show that expressions of locative relations are more resilient to late input than motion event expressions, possibly due to their relative simplicity (Talmy, 1985).

Secondly, we found that late sign language exposure has a differential impact on different types of spatial relations: Viewpoint-dependent relations are more prone to the effects of late sign language exposure compared to the viewpoint-independent relations both for late signing children and late signing adults. Similar to what has been found for describing motion events (Newport, 1998, 1990), late sign language exposure hinders the acquisition of describing viewpoint-dependent relations. However, late sign language exposure does not hinder the acquisition of describing viewpoint-independent relations. This shows that the cognitive complexity of the spatial domain modulates the patterns of late sign language acquisition and that the effects of late sign langue exposure on spatial language development are not absolute.

Moreover, we found that especially for the descriptions of viewpoint-dependent relations, the frequency of linguistic devices that differ in morphological complexity were differentially affected by late exposure. It seems that due to the morphological complexity of classifier constructions, late signing children and adults use them less frequently compared to morphologically simpler forms even in adulthood and choose simpler devices such as Other forms instead. It is also the case that while describing viewpoint-dependent relations, late signing adults become native-like in the use of simpler forms such as relational lexemes even though they are not picked up early on by late signing children.

Finally, we also found that regardless of the viewpoint of the descriptions and years of sign language exposure, children differed from adults in their choice of linguistic form use. Children overall used more Other forms. Moreover, children used less relational lexemes (another simpler form) compared to adults.

Below we discussed the implications of these findings with regard to language development, late exposure, morphological complexity, and cognitive development.

3.5.1. Late Sign Language Exposure Hinders the Acquisition of Expressions of Viewpoint-Dependent Relations but Not Viewpoint-Independent Ones

Previous research shows that native signing but not speaking children can describe viewpoint-dependent locative spatial relations in adult-like ways around 5 years of age possibly due to the iconic affordances of the modality of the sign languages (Sümer, 2015; Sümer et al., 2014). Although both types of spatial relations, (i.e., viewpoint-dependent and viewpoint-independent) are acquired early by native signing children (Sümer, 2015; Sümer et al., 2014; Sümer & Özyürek, 2020), our findings suggest that this is not the case for late signing children. Despite the iconic and body-anchored representation of locative forms to express spatial relations in TİD, deaf children still need early exposure to be able to benefit from iconicity in these forms for acquiring descriptions of viewpoint-dependent relations. Thus, iconicity cannot be taken for granted (see Cartmill et al., 2017). Our findings show that late signers *do* need early sign language exposure to benefit from iconic forms, especially for viewpoint-dependent relations.

Therefore, the results of the present study indicate that late signing children's acquisition patterns parallel the trends in spoken language acquisition with an earlier acquisition for viewpoint-independent relations than viewpoint-dependent relations. Such an earlier acquisition is argued to be due to the mapping of linguistic forms onto the already existing prelinguistic conceptual categories of containment and support (Clark, 1973; Johnston & Slobin, 1979) in which children first show an understanding of these concepts prior to language (e.g., Casasola, 2008; Casasola et al., 2003) and at around two years, they use linguistic forms for containment and support (Bloom, 1973; Bowerman, 1996a; Brown, 1973). Therefore, late signing children might already have an understanding of the viewpoint-independent relations before exposure to language and thus can easily map the linguistic forms to these concepts after two years of exposure to a sign language. However, it is argued that for viewpoint-dependent relations, conceptual development takes more time (see Benton, 1959; Harris, 1972; Piaget, 1972; Sümer, 2015). Therefore, in the case of late exposure to a sign language, the mapping of expressions for these concepts might also be delayed and this delay persists into adulthood. This finding points to a complex interplay between late language exposure and the effects of conceptual development in the spatial domain (see Berk & Lillo-Martin, 2012; Boudreault & Mayberry, 2006). Moreover, our findings also parallel the argument on the importance of maturational constraints on the receptivity of spatial semantics by L2 learners of English in spoken language acquisition (Munnich et al., 2010).

3.5.2. Morphological Complexity of the Linguistic Devices Is Differentially Affected By Late Exposure

Our findings show that the morphological complexity of the forms also plays a role in sensitivity to late exposure and in ways interacting with the conceptual complexity of the relations described. Classifier constructions, which are morphologically the most complex forms compared to relational lexemes and Other forms, are used less frequently by late signers compared to native signers for viewpoint-dependent relations but in statistically similar frequencies when describing viewpoint-independent relations. These are in line with findings from previous research on classifier constructions being vulnerable to late input for complex descriptions such as motion events (see Newport, 1988, 1990). The fact that we found hindering effects of late exposure for classifier constructions for cognitively complex relations (i.e., viewpoint-dependent relations) provides evidence for an interaction between late exposure, linguistic (i.e., morphology), and cognitive complexity of the spatial domain.

Finally, our study is the first to point out that signers also choose Other forms, which are morphologically simpler than classifier constructions in their spatial descriptions. This finding is also modulated by the late language exposure and type of spatial relation to be described. That is, late signers, both adults and children, choose these simple forms more than native signers in describing viewpoint-dependent relations but not for describing viewpoint-independent ones. Thus, despite the years of exposure to language, hindering effects of late exposure persist for language productions of some types of spatial relations.

3.5.3. Children Differ From Adults in the Use of Linguistic Devices

Regardless of the late sign language exposure, both native and late signing children, in general, differed from adults in the frequency of types of linguistic devices they used. Children used Other forms more than adults, in general. Additionally, children also differ from adults in the frequency of relational lexemes as they used less relational lexemes compared to adults. This effect also interacts with the type of spatial relation to be described and the age of exposure to language, separately.

First of all, we believe that the high frequency of Other forms used by children compared to adults gives insights into the developmental trajectory of learning to describe spatial relations. These forms, such as pointing, tracing, etc., can be considered as the *building blocks* of visual modality in learning to express spatial relations. We can generalize from this finding that signing children (both native and late) start with *simpler forms* in learning to encode locative spatial relations.

Nevertheless, when it comes to relational lexemes, although they are also simpler than classifier constructions (Arık, 2013; Perniss, et al., 2015a), children use them rarely compared to adults. This age effect also interacts with the type of spatial relation and age of exposure to language, separately. These interactions point to a complex interplay between linguistic and cognitive development of space. That is, although relational lexemes are morphologically simpler than classifier constructions, one could argue that they are semantically more complex and require more abstraction in their encoding than classifier constructions. However, we need further research to back up this claim.

3.6. Conclusion

Our study also uniquely displays these patterns for late signing children for the first time in the literature comparing them to their native signing peers as well as to late signing adults. Overall, the present study demonstrates that late sign language exposure can influence the acquisition of spatial relations for children and adults. However, this effect depends on the type of spatial relation and the type of linguistic device used. While viewpoint-independent relations are quickly learned 2 years after the exposure to a sign language in native-like ways by children and adults, acquisition of viewpoint-dependent relations takes more time. Furthermore, late signing adults become native-like in expressing viewpoint-dependent relations only in the use of morphologically simpler forms but not in more complex ones.

These findings show that linguistic expressions of spatial relations that appear later in cognitive development (i.e., viewpoint-dependent relations) might be more susceptible to the effects of late language exposure than the ones that appear cognitively earlier (i.e., viewpoint-independent relations; see Benton, 1959; Bowerman, 1996a, 1996b; Clark, 1973; Corballis & Beale, 1976; Harris, 1972; Johnston & Slobin, 1979; Piaget, 1972). This suggests that cognitive factors might be modulating which types of linguistic expressions will be influenced by late exposure and indicate the primacy of cognitive development on language development.

These results are also in line with the effects of linguistic factors modulating spatial language development and in line with previous literature showing that the morphological complexity of the forms used in sign language descriptions of space plays a role in late exposure (Newport, 1988, 1990). Moreover, these results add more evidence to the spoken language acquisition literature showing that linguistic factors (i.e., morphological complexity of the ways to express spatial relations) have the potential to guide the development of spatial language in addition to cognitive development of space (Johnston & Slobin, 1979). Nevertheless, our study goes beyond this finding and shows that in addition to morphological complexity, factors outside of language such as type of spatial relation (i.e., locatives versus motion event expressions; viewpoint-dependent versus viewpoint-independent relations) also interact with late exposure to language.

Overall, our study shows that late sign language exposure hinders the development of spatial language use in children and adults but these effects are not absolute but are modulated by cognitive and linguistic complexity, pointing to an intricate interplay of linguistic and cognitive factors in spatial language development.

However, one limitation of the current study is that we did not control for other possible factors that might differ between late and native signers, such as non-linguistic cognitive skills. We addressed this and other limitations in **Chapter 5**, where we attempted to replicate the effects of late sign language exposure on spatial language use by employing a higher number of stimuli materials that were balanced and a higher number of participants who were matched not only on age at the time of testing but also on school experience and non-linguistic cognitive skills. See **Chapter 5** for more details.

Chapter 4: Spatial Language Use Predicts Spatial Memory of Children: Evidence from Sign, Speech, and Speech-plus-gesture

This chapter is based on:

Karadöller, D. Z., Sümer, B., Ünal, E. & Özyürek, A. (2021). Spatial language use predicts spatial memory of children: Evidence from sign, speech, and speech-plus-gesture. In T. Fitch, C. Lamm, H. Leder & K. Tessmar (Eds.), *Proceedings of the 43th annual conference of the cognitive science society (CogSci 2021)* (pp. 672-678). Vienna: Cognitive Science Society.

Abstract

Previous research shows a strong relation between speaking children's exposure to spatial terms and their subsequent memory accuracy. In the current study, we further tested whether the production of spatial terms by children and adults themselves predicts memory accuracy and whether the language modality of these encodings modulates memory accuracy differently. Hearing child and adult speakers of Turkish and deaf child and adult signers of Turkish Sign Language (*Türk İşaret Dili* [TİD]) described pictures of objects in various spatial relations to each other and later tested for their subsequent memory of these pictures in a surprise recognition memory task. We found that having described the spatial relation between the objects predicted better memory accuracy. However, the modality of these descriptions in sign, speech, or speech-plus-gesture did not reveal differences in memory accuracy. We discuss the implications of these findings for the relation between spatial language, spatial memory, and the modality of encoding.

4.1. Introduction

Previous research shows that there is a strong relation between knowledge and the use of spatial language and spatial memory accuracy (e.g., Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner, 2016; Hermer-Vasquez et al., 2001; Landau, 2017; Lowenstein & Gentner, 2005; Miller et al., 2016). However, with the exception of a few studies (Abarbanell & Li, 2021; Gentner et al., 2013; Miller et al., 2016), this link has been established through studies that focus on speech alone and neglected sign languages and co-speech gestures. Visual-spatial forms of communication through sign or co-speech gestures might enhance memory more than arbitrary encodings in speech due to the visually motivated mappings between the linguistic ways to encode space and the actual spatial configuration that it refers to (i.e., iconicity). In this study, we investigate the correspondence between linguistic encoding and spatial memory accuracy of Left-Right spatial relations. We ask whether linguistic encoding of the spatial relation between objects predicts better memory for spatial relations. Moreover, given that previous research showed an advantage for learning to encode spatial relations in sign languages, as well as for gestures (such as in **Chapter 2**), here we ask whether the modality of encoding (i.e., sign, speech, and speech-plus-gesture) modulates differences in spatial memory accuracy drawing on data from TİD and Turkish.

In the remainder of this section, we review the literature on the relationship between spatial language and spatial memory, followed by a description of the similarities and differences between the linguistic encoding of spatial relations in sign, speech, and co-speech gestures, focusing on the two languages we study. Next, we review the literature showing evidence that encoding relations in the visual modality in sign and co-speech gestures (also shown in **Chapter 2**) can enhance learning to encode spatial relations compared to speech. This corroborates the idea that visual-spatial ways to encode spatial relations that ease learning to encode space might also enhance memory for spatial relations. Finally, we review previous literature on performing actions during encoding in relation to enhancing memory accuracy. Based on this literature, we derive a set of predictions considering the frequency and the modality of spatial language use modulating spatial memory accuracy.

4.1.1. Relation between Spatial Language and Spatial Memory

Children from early on start to communicate and reason about spatial relations (Landau et al., 2011). The nature of the correspondence between spatial language and spatial memory has received substantial attention from many scholars. Several studies so far provided evidence for the link between knowledge and use of specific spatial terms and spatial memory accuracy (Abarbanell & Li, 2021; Dessalegn & Landau, 2005; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Lowenstein & Gentner, 2005; Miller et al., 2016; Shusterman et al., 2011; Simms & Gentner, 2019). For instance, knowledge of spatial terms such as *Left-Right* (Abarbanell & Li, 2021; Hermer-Vasquez et al., 2001), *Next* (Miller et al., 2016), and *Middle* (Simms & Gentner, 2019) helps children perform better in spatial memory tasks that contain these spatial relations. Moreover, experimentally providing children with spatial terms has been found to increase subsequent memory accuracy (Dessalegn & Landau, 2008). For instance, Lowenstein & Gentner (2005) found that children who received instructions containing spatial terms (i.e., T*op, Middle, Bottom*) outperformed children who were not trained on these terms when tested for spatial memory both immediately and after a 2-day delay. However, this study lacks evidence as to whether the use of spatial terms by children themselves relates to their accuracy of spatial memory tasks that contain these spatial relations.

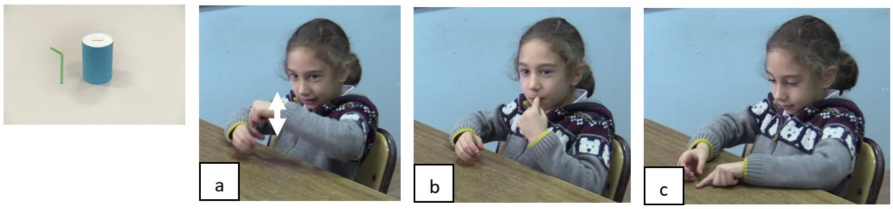
Moreover, investigations of the relation between spatial language and spatial memory focused on the linguistic encoding of space in speech alone. However, language is a multimodal phenomenon and includes co-speech gestures and sign languages that operate in visual-spatial modality. Until now, prior work did not take into account sign languages in investigating the relationship between spatial language and spatial memory. Only a prior study by Gentner et al. (2013) has compared deaf children with no language exposure (i.e., homesigners; see Goldin-Meadow, 2013) to speaking children. They found that homesigners do not encode spatial relations in language-like ways and lag behind speaking children in their memory for spatial relations. This study, however, was not conducted with signing children. Moreover, previous work also underrepresented iconic forms in spoken languages by neglecting co-speech gestures except for Abarbanell & Li (2021) and Miller et al. (2016) that focused on gestures in isolation and compared them to speech directly. These studies showed conflicting evidence for the use of gestures in isolation during a memory task by reporting either a better (Abarbanell & Li, 2021) or worse (Miller et al., 2016) memory accuracy compared to speech alone. Here, we provide new insights into this by investigating the effect of gesture together with speech (i.e., speech-plus-gesture). Focusing on speech-plus-gesture, however, is important to capture iconic aspects of spoken languages together with arbitrary speech forms especially when comparing spoken language descriptions to descriptions in a sign language (Goldin-Meadow & Brentari, 2017; Özyürek & Woll, 2019).

4.1.2. Spatial Language Use in Different Modalities

In encoding locative spatial relations between objects, sign languages incorporate linguistic forms that bear visually motivated links to actual spatial relations (e.g., Emmorey, 2002; Perniss et al., 2015a; Sümer, 2015). As reviewed in detail in **Chapter 2**, the use of classifier constructions is one of the most frequent linguistic forms that signers use (e.g., Emmorey, 2002; Janke & Marshall, 2017; Perniss et al., 2015a; Zwitserlood, 2012). These forms employ handshapes resembling the size and shape of the objects and signers place these handshapes onto the signing space in an analogue way to depict the spatial relation between the objects (see Figure 36 and see **Chapter 2** for more details for how classifier constructions are used to encode spatial relations between objects). Signers may also use other linguistic forms that encode spatial relations between objects on the signing space in visually motivated ways (see **Chapter 2** for more details, also see the coding section, and Figures 19, 20, 21 from **Chapter 3** and Figures 26, 27, 30, 31, 32 from **Chapter 3**). However, these forms do not always encode information about the size and shape of the objects involved but are only informative concerning the relative location of the objects with respect to each other.

Figure 36

An example of a classifier construction by an 8-year-old native signer of TİD encoding the spatial relation between the moneybox and the straw.



RH: MONEYBOX ---- HOLD ---- CL(round)$_{Loc}$

LH: MONEYBOX STRAW CL(long)$_{Loc}$

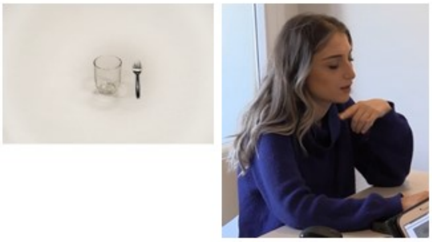
'There is a moneybox. There is a straw. The straw is to the left of the moneybox.'

Similar to sign language encodings representing spatial relations, co-speech gestures can convey information regarding the spatial relations in visually motivated ways together with speech as shown in **Chapter 2**. For instance, when talking about locations in space, speakers sometimes encode space in an ambiguous way (e.g., *Here* or *There*) while also using gestures to indicate specific locations in space (McNeill, 2005; Peeters & Özyürek, 2016). Figure 37 exemplifies the use of a directional pointing gesture that complements speech. In this example, even though speech fails to give information regarding the exact spatial relation between the objects, the directional pointing gesture to the right gestural space indicates that the fork is on the right. In such descriptions, co-speech gestures serve as a helpful tool during communication by disambiguating or highlighting information conveyed in speech or conveying information that is absent from speech (McNeill, 1992).

When it comes to speech, spatial relations between objects are represented through spatial terms that categorize spatial information through spatial nouns that have an arbitrary relation to what they refer to in the real space. For instance, in order to describe the same picture in Figure 36, an English speaker may say "the straw is to the *left* of the moneybox". Therefore, speaking children need to learn arbitrary linguistic forms that encode space in categorical ways. See **Chapter 2** for more details on how spatial relations are encoded in spoken languages in general and in Turkish in particular.

Figure 37

An example from a Turkish speaker using a pointing gesture towards the right and conveying spatial information via both speech and co-speech gesture.



Bardağ-ın yan-ın-da çatal var

Cup-GEN *side-POSS-LOC* fork there-is

'There is a fork at the side of the cup'

Note. The underlined word denotes the gesture speech overlap.

4.1.3. Advantage of Visual Modality in Spatial Language Development

Previous work (Sümer, 2015; Sümer et al., 2014, as well as findings in **Chapter 2,** have shown that there is an advantage of iconic expressions (i.e., sign and co-speech gestures) in learning to encode Left-Right spatial relations. These are novel findings as several studies reported that learning to encode Left-Right in speech is a late aspect of spatial language development for speaking children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). However, both Sümer (2015) and results of the **Chapter 2** have shown that even though Turkish-speaking 8-year-old children rarely use *Left-Right* spatial terms, they frequently use general spatial terms (e.g., *Side*) in their speech. Moreover, **Chapter 2** further showed that in addition to their descriptions with general spatial terms in speech, speaking children frequently use spatial co-speech gestures to encode spatial relations between the objects in iconic ways (see Figure 37). These studies also have shown that native signing children use iconic linguistic strategies to describe Left-Right relations in adult-like ways earlier (around age 5) than their speaking peers (around age 8) (Sümer, 2015; Sümer et al., 2014) and descriptions in sign for signing children at age 8 have been found to be more informative than descriptions in speech for speaking children (**Chapter 2**). Thus, if iconic forms are easier to acquire for encoding Left-Right relations, they might also enhance memory for spatial relations compared to arbitrary forms in speech.

4.1.4. Performing Actions and Memory Accuracy

Even though not directly studied within the spatial domain, performing actions during encoding has been found to promote better memory representations than verbal encoding[7] only for adults. This has been argued to be due to the involvement of the motor system leading to richer and/or stronger memory representations (see Cohen, 1989 and Nilsson, 2000 for reviews). Sign language descriptions and co-speech gestures may be comparable to performing actions since the execution of signs and co-speech gestures recruit hand movements that structurally resemble the movements executed in tasks that are used in performing actions. This claim has been supported by research showing that encoding through signing results in better memory accuracy compared to verbal encoding and this effect has been found to be as strong as the performing actions in adults (von Essen & Nilsson, 2003; Zimmer & Engelkamp, 2003). Consequently, the involvement of the motor system in executing these forms could lead to differences in spatial memory accuracy.

4.2. The Present Study

The present study investigates whether encoding Left-Right spatial relations between objects in a picture description task predicts subsequent recognition memory accuracy for signing and speaking children and adults. Besides, it investigates whether differences in the modality of encoding (*"speech alone versus speech-plus-gesture",* "*sign versus speech alone*", or "*sign versus speech-plus-gesture*") modulate differences in subsequent recognition memory accuracy. To address these questions, hearing child and adult speakers of Turkish and deaf child and adult signers of TİD described pictures of objects in various spatial relations to each other (please note that the procedure and dataset are identical to **Chapter 2**), after which their subsequent memory for the described pictures was tested with a surprise recognition memory task. We coded the picture descriptions for the presence of spatial relation in sign, speech, and co-speech gestures. This approach allowed us to test the relation between spatial language use and spatial memory accuracy in closely related tasks. Additionally, we measured participants' visual-spatial working memory

[7] The verbal encoding condition of these studies was operationalized as reading list of words silently (Zimmer & Engelkamp, 2003) or hearing list of words that was read to participants (von Essen & Nilsson, 2003).

span via the computerized version of the Corsi Block Tapping Task in forward order to ensure similarities across deaf signers and hearing speakers.

4.2.1. Predictions

Following previous research showing a strong relation between spatial language use and spatial memory, we expect encoding the spatial relation in picture descriptions compared to not encoding it predicts higher memory accuracy than not encoding the spatial relation in the descriptions for both signers and speakers.

When the modality of encoding is concerned, we expect descriptions in sign and descriptions in speech-plus-gesture to predict better memory accuracy than speech alone descriptions due to iconicity of the linguistic encoding representing spatial information directly and/or the activation of the motor system during linguistic encoding that may create stronger memory representations. Furthermore, when memory accuracy of the descriptions in sign versus speech-plus-gesture are considered, we foresee two possibilities: Descriptions in sign and speech-plus-gesture might generate equal memory accuracy. This might be because taking gestures into account helps better represent spoken languages by incorporating iconic forms representing spatial information directly and also employing motor system in using gestures. Alternatively, signers might outperform speakers even when speakers' gestures are taken into account due to the conventional and obligatory ways to encode space in sign but not in co-speech gestures.

4.3. Method

The methods reported in this study have been approved by the Ethics Review Board of the Radboud University, Nijmegen, The Netherlands and Survey and Research Commission of the Republic of Turkey Ministry of National Education, Turkey. The methodology is identical to **Chapter 2** except for minor differences for the purpose of the memory analyses. We will point out the similarities and differences between the current study and the study reported in **Chapter 2** concerning participants, selected stimuli items for this study, procedure, and coding in the below sections.

4.3.1. Participants

Participants were identical to **Chapter 2**. That is, data were collected from 24 child (14 Female, Mean Age = 8;6) and 23 adult (14 Female, Mage = 35;9) monolingual hearing speakers of Turkish and 21 child (12 Female, Mean Age = 8;5) and 26 adult (21 Female, Mage = 29;10) native deaf signers of TİD. All deaf participants were profoundly deaf and acquired their language from their deaf parents following birth. At the time of testing both hearing and deaf children have been attending primary school for 2 years.

Speaking and signing participants were compared to ensure similarity in terms of age and visual-spatial working memory span (i.e., Corsi Block Tapping Task). Bayesian t-tests assessed the probability of the mean difference (M_{DIFF}) greater than zero and less than zero using the R package *BayesianFirstAid* (version 0.1; Bååth, 2014) in R (R Core Team, 2018). Signing and speaking children were similar in age (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.556, M_{DIFF} (5) < 0: p = 0.444) and visual-spatial working memory (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.972, M_{DIFF} (5) < 0: p = 0.280). Signing and speaking adults were also similar in age (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.736, M_{DIFF} (5) < 0: p = 0.264) and visual-spatial working memory (Bayesian two sample t-test: M_{DIFF} (-5) > 0: p = 0.866, M_{DIFF} (5) < 0: p = 0.134).

4.3.2. Materials

Stimuli used in the description and familiarization tasks were identical to **Chapter 2**. In addition to these tasks, the current chapter also includes a recognition memory task. Identical to **Chapter 2**, stimuli of the description task and the familiarization task consisted of 84 displays with 4 pictures showing the same two objects (Figure and Ground) in various spatial configurations (i.e., Left-Right-Front-Behind-In-On). Ground objects (e.g., jar) were always in the center of the pictures and Figure objects (e.g., lemon) changed their location with respect to the Ground Objects. As a result, 4 pictures in one display differed only in terms of the position of the Figure object. This manipulation aimed to foreground spatial relations between the objects rather than the objects themselves and allowed us to ensure that participants mentioned the spatial relation between the objects as a distinguishing feature of the target picture in their descriptions. Each display had one target picture indicated by an arrow (Figure 6a from **Chapter 1**). Twenty-eight of the displays were the experimental displays that had a Left-Right spatial configuration of the objects (e.g., the pencil is to the *left* of the paper). Half of the experimental displays (i.e., Non-contrast displays) had only one picture with Left-Right spatial configuration, other pictures in the display depicted In, On, Front, or Behind configurations. The remaining half (i.e., Contrast displays) had two pictures in Left-Right spatial configuration (if the objects in the target picture showed Left spatial configuration, one another picture in the display showed Right spatial configuration or vice versa), other pictures again depicted In, On, Front, or Behind configurations. We included different types of displays as a manipulation to encourage participants to provide descriptions as informative as possible that distinguish the target picture among the other alternatives. Moreover, in an attempt to avoid explicit attention to the Left-Right spatial configurations, we used filler displays (n = 56). Filler displays consisted of target items showing Front (n = 14), Behind (n = 14), In (n = 14) and On (n = 14) spatial configurations between the objects. All displays were piloted to ensure that both children and adults could identify and name the objects. Within all 84 displays, Figure objects (e.g., pen) were presented only once. Ground objects (e.g., cup) were presented 4 times but always paired with other Figure objects (e.g., cup-pencil, cup-egg, cup-fork, cup-chocolate). The same Ground objects were only presented twice in a row. Moreover, the same spatial configuration as a target picture was presented only twice in a row to avoid biases to one type of spatial relation. Display order and the locations of the pictures in each display were randomized across each participant. Finally, there were two sets of displays with the same Ground objects but with different Figure objects. All other configurations were similar across the two sets.

Stimuli of the memory task consisted of a sample of the same displays (n = 54) without the arrow. Display order and the arrangement of the 4 pictures in one display were randomized for the recognition memory task (Figure 6b from **Chapter 1**). Initially, we piloted the memory task with the full set of displays (N = 84) used in the description task. This resulted in floor levels of memory accuracy for children. Next, we piloted the memory task with half of the displays in the description task (n = 42). This, however, resulted in ceiling performance for adults. Finally, we optimized the number of displays to 54 which includes 20 target pictures. Pilot tests showed no ceiling or floor performance for adults and/or children.

4.3.3. Procedure

The procedure is identical to **Chapter 2** except in the current study there are two additional tasks (i.e., Distractor Task and Memory Task). Please see Figure 9 from **Chapter 1** for the general overview of the procedure. All experimentation (i.e., Familiarization Task, Description Task, Memory Task, Corsi Block Tapping Task, and Flanker Task for adults[8]) was administered via Dell laptop with software Presentation NBS 16.4 (Neurobehavioral Systems, Albany, CA). The description task was video-recorded from the front and side-top angles to allow for sign coding. Each participant was tested in a quiet room. All instructions were given orally in Turkish to speakers by a Turkish speaking adult and in TİD to signers by a deaf adult signer of TİD. No written instructions were used to avoid misunderstandings by signing participants. The language status of the addressee was also matched with that of the participants.

4.3.3.1. Familiarization Task

The procedure of the familiarization task was identical to **Chapters 2 and 5.** Please see **Chapter 2** for the details.

4.3.3.2. Description Task

The procedure of the description task was identical to **Chapters 2 and 5**. Please see **Chapter 2** for the details.

4.3.3.3. Distractor Task

Following the description task, we used the Flanker Task as a distractor between the Description and Surprise Memory Tasks to avoid memory effects due to recency. For adults, we used the original version of the Flanker Task (Eriksen & Eriksen, 1974), for children we used the child-friendly version with colored fish (Rueda et al., 2004).

4.3.3.4. Memory Task

Later, participants received the recognition memory task as a surprise in order to avoid possible effects on their linguistic production. In this task, participants were given the same displays and asked to click on the picture that they had previously described by using the mouse. The rationale for having this task as a

[8] Children received the Flanker task on the same laptop but with E-prime software.

surprise is to eliminate possible influences on the production performance. Participants received the trials one by one. New trials started as participants clicked on the pictures to make a selection. Participants completed the task at their own pace. That is why we did not analyze the reaction time of the responses but focus only on accuracy scores.

4.3.3.5. Visual-Spatial Working Memory Task

After the memory task, participants received the computerized version of the Corsi Block Tapping Task (Corsi, 1972) in forward order to ensure that speaking children and adults have similar visual-spatial working memory spans to their native signing counterparts. This is important in looking back at studies showing mixed evidence for the differences in working memory across speakers and signers (see Emmorey, 2002 & Marshall et al., 2015).

4.3.4. Annotation and Coding: Spatial Descriptions

Description data of the current chapter were identical to **Chapter 2**. However, there were some differences in the number of stimuli items selected for memory analyses and coding categorizations for the relevant descriptions in relation to which memory responses were analyzed.

The first difference between the current chapter and **Chapter 2** is that, in the current chapter, we only considered production data of the 20 items that we had collected the memory data, but production comparisons of **Chapter 2** were based on the data of 28 items.

The second difference between the current chapter and **Chapter 2** is the way we grouped the production data of hearing participants. In the current chapter, unlike in **Chapter 2**, we initially grouped descriptions as to whether or not they include spatial encoding. Descriptions that are coded as having spatial encoding include descriptions with a) *Left-Right* spatial terms only, b) a general spatial term *Side* only, and c) descriptions where speech and gesture are informative as a composite utterance (*Left*+Gesture, *Right*+Gesture, *Side+ Gesture*). The remaining descriptions were coded as having no spatial encoding (e.g., descriptions with missing spatial relation and descriptions with other spatial nouns such as *Front*). This categorization is slightly different than in **Chapter 2** where we were mainly interested in informativeness of the descriptions, whereas in this current study, were interested in whether the modality of linguistic expression predicted memory.

Finally, the third difference between the current chapter and **Chapter 2** is the way we categorized descriptions in speech and speech-gesture combinations. In the current chapter, since we wanted to compare whether descriptions in different modalities predict differences in spatial memory, we wanted to categorize speech descriptions consisting only of speech (i.e., speech alone). Accordingly, in the current chapter speech only descriptions contain specific spatial nouns (i.e., *Left-Right*) and do not contain any spatial gestures, which is different than what we had for the speech category in **Chapter 2**. To reflect the difference in the coding between **Chapter 2** and the current chapter, we named this new category as Speech alone. Moreover, we also grouped speech-gesture combinations differently than that of **Chapter 2.** In the current chapter, these descriptions include either specific or general spatial nouns with gestures (i.e., *Left*+Gesture, *Right*+Gesture, Side+Gesture). We named this new category as Speech-plus-gesture to reflect the difference between the current chapter and **Chapter 2**. The coding of descriptions in sign were identical between the current chapter and **Chapter 2**. Note that all spatial encodings in sign give exact spatial information. In this way, we could investigate whether spatial relations described in speech alone lead to different memory outcomes compared to those that are multimodal (speech-plus-gesture), in which gesture might enhance memory through action and iconic representation. Moreover, we could also compare whether or not descriptions that encode spatial relations iconically (i.e., speech-plus-gesture versus sign) lead to differences in spatial memory. Production patterns in the current chapter reflect the comparative findings between signers and speakers in **Chapter 2** (See Tables 10 and 11).

Table 10

Percentages of the descriptions in each category for speakers.

	Spatial Encoding			No Spatial Encoding
	Speech alone (*Left-Right)*	Speech alone (Side)	Speech-plus-gesture (*Left*+Gesture; *Right*+Gesture; *Side*+Gesture)	
Children	14%	19%	63%	4%
Adults	62%	3%	32%	3%

Table 11

Percentages of the descriptions in each category for signers.

	Spatial Encoding	No Spatial Encoding
Children	90%	10%
Adults	99%	1%

4.4. Results

4.4.1. Memory Accuracy

Recognition memory data were analyzed with generalized binomial linear mixed-effects modeling (*glmer*) with random intercepts for Subjects and Items.[9] All models were fit using *lme4* package (Bates et al., 2014) in R (R Core Team, 2018). This mixed-effects approach allowed us to take into account the random variability that is due to having different participants and items. We did not include random slopes in our models because doing so either did not increase the model fit or the model was testing a fixed effect that varied between subjects and could not be added as a random slope. We did our comparisons separately for children and adults in order to avoid possible confounds affecting the memory performance due to age.

4.4.1.1. Memory Accuracy in relation to Spatial Encoding

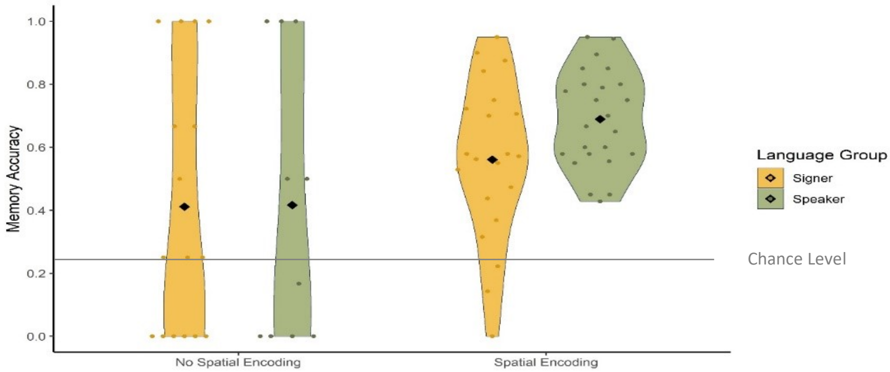
In this section, we do not report any comparisons for adults because Spatial Encoding[8] is not suitable to be used as a fixed effect for predicting memory accuracy since both signing and speaking adults encoded the spatial relation between the items in 99% and 97% of the cases, respectively (see **Chapter 5** for a similar strategy). For children, we analyzed whether or not having encoded the spatial relation between the objects related to recognition memory accuracy of signers and speakers differently. We used a glmer model to test the fixed effects of Spatial Encoding (Spatial Encoding, No Spatial Encoding) and Language Group (Signer, Speaker) on binary values of Memory Accuracy (1 = Accurate, 0 = Not Accurate) at the item level (Figure 38). Fixed effects of Spatial Encoding and Language Group were analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Spatial Encoding (β = 1.04, SE = 0.34, p < 0.003) in which regardless of the Language Group, descriptions that encoded spatial relations related to higher memory accuracy compared to descriptions that did not encode a spatial relation. There was no effect of

[9] Display Type (Contrast, Non-contrast) was used as a fixed effect in all of the initial models, we removed it from all the models reported in this chapter as (1) it did not turn out to be significant and (2) did not improve the model fit.

Language Group (β = 0.28, *SE* = 0.42, *p* = 0.516) and no interaction between Spatial Encoding and Language Group (β = 0.69, *SE* = 0.68, *p* = 0.309).

Figure 38

Memory accuracy of all descriptions across Language Group and Spatial Encoding[10] for Children.



Notes. Colored dots represent the mean memory accuracy for each participant. The black diamond represents the mean memory accuracy of the group. The width of the violins represents the density of the data distribution. The length of the violins depicts the range of the data points.

4.4.1.2. Memory Accuracy in relation to Modality of Encoding

Next, we focused only on the descriptions that include spatial encoding and investigated to what extent the modality of information conveyed in the descriptions of signers and speakers related to subsequent memory accuracy. To do so, we did three comparisons. First, we compared the memory accuracy of descriptions with Speech alone versus Speech-plus-gesture. Next, we compared the memory accuracy of descriptions with Sign versus Speech alone. Last, we compared the memory accuracy of descriptions with Sign versus Speech-plus-gesture.

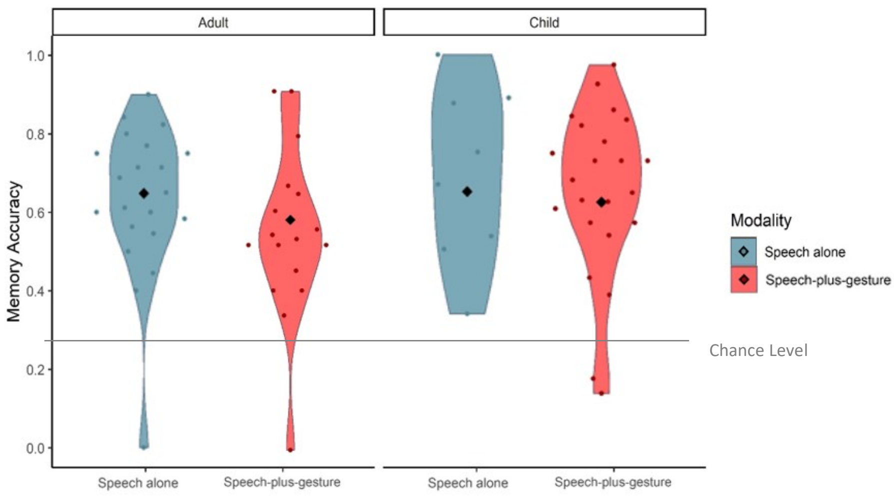
First, we analyzed a subset of data which includes speech alone descriptions with *Left-Right* spatial nouns of speakers (14% of the total descriptions of speaking children and 62% of the total descriptions of speaking adults; see Table 10 above) in comparison to another subset of data which includes speech-

[10] These include *Left-Right* spatial nouns (14%), general noun *Side* (19%), and speech-plus-gesture (63%).

plus-gesture descriptions by speakers (63% of the total descriptions of children and 32% of the total descriptions of adults; see Table 10 above). We tested to what extent the Modality of the encoding (Speech alone versus Speech-plus-gesture) related to memory accuracy. We used separate *glmer* models for adults and children to test the fixed effect of Modality (Speech alone, Speech-plus-gesture) on binary values of Memory Accuracy (1 = Accurate, 0 = Not Accurate) at the item level (Figure 39). The fixed effects of Modality were analyzed with centered contrasts (-0.5, 0.5). There was no effect of Modality (*Children*: β = -0.07, *SE* = 0.40, *p* = 0.861; *Adults*: β = 0.20, *SE* = 0.23, *p* = 0.372), in which encoding via Speech alone or Speech-plus-gesture did not lead to statistically significant differences in memory accuracy for both adults and children.

Figure 39

Memory accuracy of descriptions across Speech alone and Speech-plus-gesture.

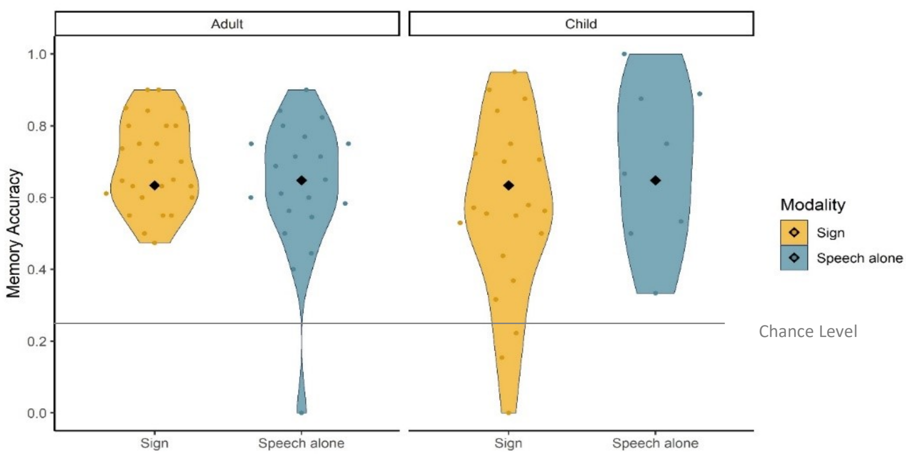


Notes. Colored dots represent the mean memory accuracy for each participant. The black diamond represents the mean memory accuracy of the group. The width of the violins represents the density of the data distribution. The length of the violins depicts the range of the data points.

Second, we analyzed a subset of data which includes speech alone descriptions with *Left-Right* spatial nouns of speakers (14% of the total descriptions of speaking children and 62% of the total descriptions of speaking adults; see Table 10 above) in comparison to all descriptions in sign for signers (90% of the total descriptions of signing children and 99% of the total descriptions of signing adults; see Table 11 above). We tested to what extent the Modality of the encoding (Sign versus Speech alone) related to memory accuracy. We used separate *glmer* models for adults and children to test the fixed effect of Modality (Sign, Speech alone) on binary values of Memory Accuracy (1 = Accurate, 0 = Not Accurate) at the item level (Figure 40). The fixed effects of Modality were analyzed with centered contrasts (-0.5, 0.5). There was no effect of Modality (*Children*: $\beta = 0.61$, $SE = 0.56$, $p = 0.278$; *Adults*: $\beta = -0.16$, $SE = 0.18$, $p = 0.383$), in which encoding via Sign or Speech alone did not lead to statistically significant differences in memory accuracy for both adults and children.

Figure 40

Memory accuracy of descriptions across Sign and Speech alone.

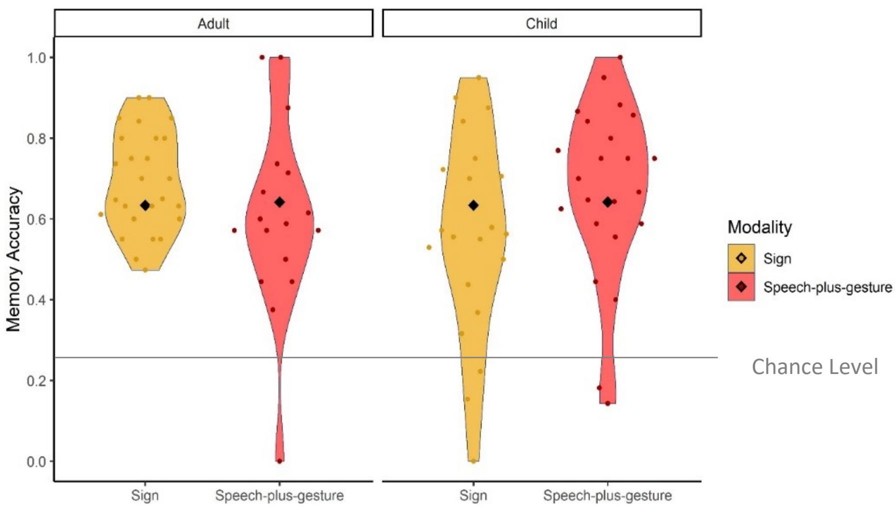


Notes. Colored dots represent the mean memory accuracy for each participant. The black diamond represents the mean memory accuracy of the group. The width of the violins represents the density of the data distribution. The length of the violins depicts the range of the data points.

Lastly, we analyzed another subset of data which includes speech-plus-gesture descriptions by speakers (63% of the total descriptions of children and 32% of the total descriptions of adults; see Table 10 above) in comparison to all descriptions in sign for signers (90% of the total descriptions of signing children and 99% of all descriptions of signing adults; see Table 11 above). We tested to what extent the Modality of the encoding (Sign versus Speech-plus-gesture) related to memory accuracy. We used separate glmer models for adults and children to test the fixed effect of Modality (Sign, Speech-plus-gesture) on binary values of Memory Accuracy (1 = Accurate, 0 = Not accurate) at the item level (Figure 41). The fixed effects of the Modality were analyzed with centered contrasts (-0.5, 0.5). There was no effect of Modality (*Children:* β = 0.58, *SE* = 0.36, *p* = 0.106; *Adults:* β = -0.41, *SE* = 0.22, *p* = 0.066): encoding via Sign or Speech-plus-gesture did not predict differences in memory accuracy for adults and children.

Figure 41

Memory accuracy of descriptions across Sign and Speech-plus-gesture.



Notes. Colored dots represent the mean memory accuracy for each participant. The black diamond represents the mean memory accuracy of the group. The width of the violins represents the density of the data distribution. The length of the violins depicts the range of the data points.

These results suggest first of all that regardless of the language used in the description, encoding the spatial relation in the description related to higher recognition memory accuracy than not encoding spatial relation for children (note that we did not report findings for adults as adult data did not show a variation for spatial encoding). Moreover, the type of spatial information conveyed in the description via different modalities did not lead to statistically significant differences in memory accuracy for both adults and children.

4.5. Discussion

In this study, we investigated whether linguistic encoding of the spatial relation between objects predicted better memory for the spatial relation between objects and whether this effect differed across signing and speaking children. Furthermore, we tested to what extent the modality of encoding predicted memory accuracy tested separately for children and adults. We had two key findings: First, encoding a spatial relation predicted higher memory accuracy both for signing and speaking children. Please note that we could not compare signing and speaking adults as their data did not show a variation for spatial encoding. Second, the modality of encoding (Speech versus Speech-plus-gesture, Sign versus Speech alone, or Sign versus Speech-plus-gesture) did not predict statistically significant differences in memory accuracy.

In the sections that follow, we discuss the implications of these findings concerning the relation between spatial language and memory, differences in linguistic and cognitive representations of Left-Right in speech compared to sign and gesture, and possible effects of task demands on the results.

4.5.1. Spatial Language Use but Not Its Modality Predicts Higher Memory Accuracy

As for the relation between spatial language and memory, our findings provide further evidence to the view that encoding space through language predicts better memory (see Dessalegn & Landau, 2008; Gentner, 2016; Lowenstein & Gentner, 2005; see also Ünal & Papafragou, 2016 for a general discussion on language and cognition). Here, we showed that such an enhanced representation predicted stronger or richer memory as evidenced by higher accuracy when the spatial relation between the objects was present regardless of the modality of the representation. Moreover, our study is first to investigate the relation between producing spatial terms by children *themselves* to encode space and later accuracy in a memory task that involves these spatial relations. Extending the previous work that provided children with spatial terms experimentally and tested later memory accuracy (e.g., Dessalegn & Landau, 2008; Lowenstein & Gentner, 2005), we show that spontaneous encoding of space by children *themselves* relates to better memory accuracy. With this finding, we also extend the literature on spatial language use and spatial memory abilities of children (e.g., Abarbanell & Li, 2021; Hermer-Vasquez et al., 2001; Miller et al., 2016; Simms & Gentner, 2019) in a memory task that involves one-to-one correspondence to the linguistic encoding task.

Our findings also provide further evidence to the literature showing a strong relation between encoding with speech and later memory accuracy (Slamecka & Graf, 1978) and extend this to encoding through sign and gesture (see also Gentner et al, 2013 and ter Bekke et al., 2019). We also extend these findings to the domain of space (Clark, 1973), where the modality of encoding might have an impact due to the visually motivated link between the linguistic form and its meaning while encoding via sign and gesture but not speech. However, it seems that regardless of the modality of encoding, once children encode the spatial relation in their descriptions, they have better memory representations compared to cases where they do not encode the spatial relation.

First, comparing memory accuracy of descriptions in speech alone versus sign and speech alone versus speech-plus-gesture, we did not find differences between memory accuracy of descriptions that are encoded via speech alone versus sign or speech versus speech-plus-gesture. Despite the literature that shows a facilitating effect of encoding that incorporates actions on memory accuracy (Cohen, 1989; Nilsson, 2000) as well as the facilitating effect of encoding via sign over verbal encoding (Essen & Nilsson, 2003; Zimmer & Engelkamp, 2003) that might lead to stronger memory representations while describing via sign or speech-plus-gesture, encoding Left-Right in speech has its own challenges for speaking children. It might be that encoding space through spatial terms that categorize the spatial relation in arbitrary ways requires more effortful processing than simply depicting the spatial relation in iconic ways. Hence, this results in memory representations obtained from encoding with speech that are equally strong to encoding via iconic forms. This is especially plausible for descriptions of Left-Right relations in which children are reported to have difficulties in cognitive and linguistic encoding (Abarbanell & Li, 2021;

Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014) possibly due to the lack of any cues to differentiate between symmetrical nature of Left and Right (see Grigoroglou et al., 2019 for the discussion on pragmatical cues to distinguish Front and Back). In order to further investigate the relationship between spatial language use and spatial memory, another approach could be to focus on cognitively simpler spatial relations such as In-On-Under to see if these effects can be replicated.

Next, comparing sign to speech-plus-gesture, this study offers a unique and comprehensive way of investigating visually motivated forms of encoding in spoken languages by investigating speech and co-speech gestures together to predict better spatial memory accuracy. Previous studies showed conflicting evidence for the use of gestures alone during a memory task by reporting either a better (Abarbanell & Li, 2021) or worse (Miller et al., 2016) memory accuracy compared to speech alone. Here, we provided new insights into this literature by investigating the effect of gesture together with speech in comparison to sign. We find that encoding via sign and speech-plus-gesture predicted equal memory accuracy.

4.5.2. Lack of memory effects due to possible interplay between production and picture superiority effect

It is possible that our paradigm could not detect the subtle differences in memory across modalities. It is possible that having used pictures as the stimuli material (*picture superiority effect*; Paivio et al., 1968) coupled with asking participants to describe the target pictures during encoding (*production effect*; Conway & Gathercole, 1987) might have boosted memory accuracy (see Zormpa et al., 2019 for the complex interplay between picture superiority and production effects in psycholinguistics research) and washed out the possible effects. It is also possible that not imposing participants to respond quickly in the memory task might have diminished the differences in memory accuracy, where participants took their time to find the correct answer. Future studies should consider restricting the timing of responses to capture subtle effects if any.

4.6. Conclusion

In conclusion, the present study contributes new evidence to the link between the use of spatial language and later memory accuracy of children. Moreover, our findings show for the first time that the use of spatial language by children *themselves* predicts better accuracy in memory tasks that require these spatial relations. However, the modality of encoding via sign, speech, or speech-plus-gesture does not further modulate differences in memory accuracy of children and adults.

Chapter 5: Late Sign Language Exposure does not modulate the Relation between Spatial Language and Spatial Memory in Deaf Children and Adults

This chapter is based on:

Karadöller, D. Z., Sümer, B., Ünal, E. & Özyürek, A. (Provisionally Accepted). Late sign language exposure does not modulate the relation between spatial language and spatial memory in deaf children and adults. *Memory and Cognition.*

Abstract

Prior work with speaking children shows that their spatial language and cognition are related systems and that spatial language use enhances their spatial memory. Here, we further investigate the extent of this relationship in signing deaf children and adults and ask if late sign language exposure, as well as the frequency and the type of spatial language use that might be affected by late exposure, modulate subsequent memory for spatial relations. To do so, we compared spatial language and memory of 8-year-old late signing children (after 2 years of exposure to a sign language at the school for the deaf) and late signing adults to their native signing counterparts. We elicited picture descriptions of Left-Right relations in Turkish Sign Language (*Türk İşaret Dili* [TİD]) and measured the subsequent recognition memory accuracy of the described pictures. Results showed that late signing adults and children were statistically similar to their native signing counterparts in how often they encoded the spatial relation. However, late signing adults but not children differed from their native signing counterparts in the type of spatial language they use. However, neither late sign language exposure nor the frequency and the type of spatial language use modulated spatial memory accuracy. Therefore, even though late language exposure seems to influence the type of spatial language use, this does not predict subsequent memory for spatial relations. We discuss the implications of these findings concerning spatial language, spatial memory, and late language exposure.

5.1. Introduction

Children from early on communicate and reason about spatial relations. Prior work shows that there is a tight relation between these two systems and that children's spatial language might enhance their cognition such as their spatial memory (Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner, 2016; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Karadöller et al., 2021 as reported in **Chapter 4**; Landau, 2017; Lowenstein & Gentner, 2005; Miller et al., 2016). However, this evidence comes mostly from speaking children, who already have access to language from birth and thus does not address whether being exposed to a language early or later in childhood can influence this relationship (but see Gentner et al., 2013). This relationship can be studied by focusing on the language acquisition patterns of deaf children. The majority of deaf children (90%) are born to hearing parents and do not have immediate exposure to a signed or a spoken language (Mitchell & Karchmer, 2004) – even with hearing aids, which may not provide enough access to the surrounding speech (Hall et al., 2019). In such situations, many deaf children with hearing parents are exposed to a sign language later in life and mostly after entering a school for the deaf, especially in non-western countries. Consequently, they are considered to be late signers because they lack immediate sign language exposure following birth. By contrast, deaf children with deaf parents are considered to be native signers, as they are exposed to a sign language from birth onwards by their caregivers.[11]

In this study, drawing evidence from deaf individuals who vary in the timing of exposure to a sign language we investigate whether late versus early exposure to a sign language (Turkish Sign Language, *Türk İşaret Dili* [TİD]) predicts spatial language use as well as its relation to spatial memory. This allows us to investigate the relation between spatial language and memory in ways that would not have been possible by studying children who have immediate access to a spoken language.

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[11] Following several scholars (e.g., Lillo-Martin & Henner, 2021; Mayberry, 1998; Newport, 1990), we use the term *native* to refer deaf individuals who have a sign language exposure immediately following birth from their signing deaf parents. We use the term *late* to refer deaf individuals who have a sign language exposure mostly at the school for the deaf from their deaf signing peers.

Previous research has shown that preceding language exposure, deaf children of hearing parents in Turkey with no access to a sign or a spoken language lacked linguistic means to communicate about spatial relations and lagged behind speaking children in a spatial memory task (Gentner et al., 2013). Further research showed that after 2 years of exposure to TİD, that is after starting the school for the deaf, another group of deaf children in Turkey was able to describe spatial relations as frequently as native signing children using conventional linguistic forms (Karadöller et al., 2021 as reported in **Chapter 3**). However, the type of linguistic forms used by this group of late signers somewhat differed from that of native signers. Nevertheless, this previous research by Karadöller et al. (2021) used a variety of spatial relations (i.e., locative relations such as Left-Right, In-On-Under) to elicit picture descriptions that were not balanced in terms of the number of stimuli items and tested relatively few participants that were not controlled in certain aspects such as school experience or other non-linguistic cognitive skills. Furthermore, it did not test whether late signing children after 2 years of sign language exposure had comparable spatial memory performance to their native signing peers in relation to their linguistic performance.

Therefore, our first goal here is to offer further empirical evidence on the differential effects of late versus early exposure on spatial language use in children and adults by addressing the limitations of prior work. To do so, we use a more controlled set of stimuli of locative relations and test a higher number of native and late signers who are matched in several criteria (e.g., cognitive skills, schooling experience, etc.). Our second goal is to investigate whether the effects of late versus early exposure to language extend beyond the domain of spatial language and predict spatial memory accuracy. We address these goals by comparing deaf children and adults who are late and native signers of TİD on the frequency and the type of locative forms used in picture descriptions as well as the subsequent memory accuracy of the pictures they described.

We focus on the linguistic encoding of Left-Right relations, which has been found to be both cognitively and linguistically challenging for children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Martin & Sera, 2006; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014) and also seems to differ across late versus early exposure to a sign language in terms of the type of linguistic form used to express such relations (Karadöller et al., 2021 as reported in **Chapter 3**). The previous chapter has shown that there is a relationship between encoding Left-Right relations in language and subsequent memory of these relations across speakers and signers (Karadöller et al., 2021 as reported in **Chapter 4**). Yet, late language acquisition might modulate this relationship possibly due to shorter experience with the language or use of different linguistic forms due to late exposure (see also Gentner et al., 2013).

In the following sections, we first review the literature on the relation between spatial language and spatial memory followed by a description of the linguistic encoding of spatial relations in sign languages in general and specifically for TİD. Later, we review the literature on the development of linguistic encoding in the case of late and early language exposure. Based on this literature, we build our predictions regarding the relation between spatial language and spatial memory accuracy considering late sign language exposure, as well as the frequency and the type of language use, as factors possibly influencing this relationship.

5.1.1. Relation between Spatial Language and Spatial Memory

Several studies reported that knowledge and use of spatial terms are important predictors of speaking children's spatial reasoning in general and memory in particular (Abarbanell & Li, 2021; Cassasola et al., 2020; Dessalegn & Landau, 2008; Gentner, et al., 2013; Hermer-Vasquez et al., 2001; Karadöller et al., 2021 as reported in **Chapter 4**; Loewenstein & Gentner, 2005; Miller et al., 2016; Pruden, et al., 2011; Shusterman et al., 2011; Simms & Gentner, 2019; Turan et al., 2021). These studies suggested that there is a tight relationship between spatial language and spatial memory (see also **Chapter 1** for a discussion). Some of these studies have shown correlational evidence for the use of spatial terms and accuracy in tasks that require the memory of spatial relations (e.g., Hermer-Vasquez et al., 2001). Some others have shown experimental evidence that providing children with spatial terms (e.g., *Left*) that highlight spatial features of target scenes improved memory for these scenes when tested immediately after the presentation of the scenes (Dessalegn & Landau, 2008). Similarly, providing children with spatial terms (e.g., *Middle*) before the experiment by the experimenters themselves resulted in better memory accuracy shortly after or even after two days (Lowenstein & Gentner, 2005). In Lowenstein & Gentner (2005), children were presented with two boxes (hiding box and finding box) that contain a card in each tier. First, children watched the experimenter placing a card in the hiding box and then were asked to find the card in the finding box. The card was always in the same spatial location (*Top, Middle, Bottom*) in the two boxes. Prior to the task, half of the children played with the experimenter by using spatial terms (e.g., I am putting the winner *on* the box). The other half did not receive instructions that included spatial terms (e.g., I am putting the winner right here). Children who received instructions containing spatial terms outperformed the children who did not receive spatial terms when tested on the same day of the play session and even two days later. However, in this study, children were provided with spatial terms by the instructor. Hence, these findings leave open whether the use of spatial terms by children *themselves* predicts their memory accuracy. Moreover, in **Chapter 4** (Karadöller et al., 2021), we showed that encoding the spatial relation with language predicted better memory accuracy of the spatial relations compared to not encoding the spatial relation for both signing and speaking children who had access to language following birth by their signing and speaking parents, respectively. However, this study did not show evidence for whether encoding with different modalities (i.e., sign, speech, speech-plus-gesture) modulates the relationship between spatial language use and subsequent spatial memory.

All of the above studies focused on speaking/signing children who had access to language following birth. Only one study investigated whether or not being exposed to language predicts children's performance in a spatial memory task (Gentner et al., 2013). In this study, Turkish deaf children who did not have a conventional language exposure were compared to same-age Turkish speaking children using the same task as in Lowenstein & Gentner (2005) mentioned above. This time the task only contained instructions without spatial terms for speaking children and for deaf children it contained pointing gestures to indicate locations as they did not have a conventional language. Results showed that deaf children without language access did not have gestures resembling linguistic strategies used in sign languages to convey spatial relations and they performed significantly lower than speaking children and barely exceeded the chance level. This suggested a possible relation between spatial language use and spatial memory performance. However, one major drawback of this study was to compare deaf children with no language exposure to speaking children where both deafness and language access differed between the groups.

Following the above mentioned studies investigating the relation between spatial language and memory, there is an open question regarding the relation between spatial language and spatial memory in signing deaf children and whether late exposure to a sign language modulates this relation (e.g., 2 years; see Karadöller et al., 2021 as reported in **Chapter 3** for a similar approach). A further question is whether the relation between spatial language and memory is predicted by the frequency and the type of spatial language used by native and late signing children and adults as these have been found to be affected by late sign language exposure (Karadöller et al. 2021 as reported in **Chapter 3**).

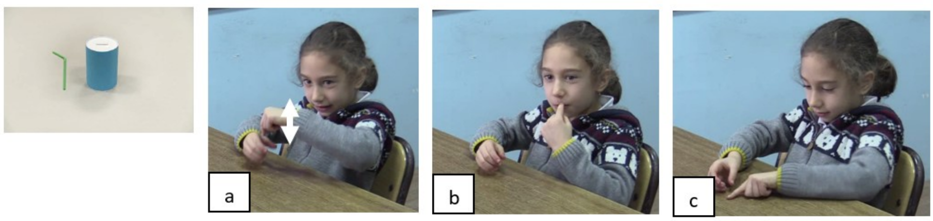
5.1.2. Spatial Language Use in Sign Languages

In sign languages, spatial relations between objects are most frequently encoded by classifier constructions (e.g., Emmorey, 2002; Manhardt et al., 2020; Perniss et al., 2015a; Sümer, 2015; Zwitserlood, 2012). These constructions encode the size and shape of the objects through handshape classifications and allow signers to position these handshapes to represent the relative locations of these objects on the signing space in an analogue way to the real space. The position and the location of the hands in signing space communicate information about the location of the objects (e.g., Emmorey, 2002; Janke & Marshall, 2017; Perniss, 2007; Supalla, 1982; Zwitserlood, 2003) and the classifiers themselves are expressed by handshapes that classify entities by representing their salient characteristics, predominantly size and shape features (Emmorey, 2002; Supalla, 1982; Zwitserlood, 2003; 2012). Morphological complexity in these forms is argued to be due to several factors such as the use of classifier handshapes (Bernardino, 2006; Brentari et al., 2013; Kantor, 1980; Morgan et al., 2008; Slobin et al., 2003; Supalla, 1982; Tang et al., 2007), the use of a location morpheme by placing hands on sign space (Schick, 1990; Zwitserlood, 2003), and representing the relative locations of Figure and Ground objects simultaneously in a classifier construction (Supalla, 1982; Slobin et al., 2003; Engberg-Pedersen, 2003; Tang et al., 2007; Morgan et al., 2008).

To illustrate, in order to describe the spatial relation between the objects in Figure 42, the signer first introduces the lexical signs for the moneybox (Figure 42a) and straw (Figure 42b) and later chooses classifier handshapes that represent the size and shape of the moneybox (i.e., round handshape) and straw (i.e., elongated handshape). Next, she positions her hands on the signing space to represent the spatial relation between these objects in an analogue way to the real space (Figure 42c). Thus, sign language encodings of space incorporate a visually motivated meaning mapping between the linguistic form and what it refers to in the real space (so-called *iconicity*). These are also known to be morphologically complex structures as the handshapes classify the size and shape of the objects located on the sign space (Zwitserlood, 2012).

Figure 42

An example of a classifier construction by an 8-year-old native signer of TİD to encode the spatial relation between the moneybox and the straw.



RH: MONEYBOX ---- HOLD ---- CL(round)$_{Loc}$

LH: MONEYBOX STRAW CL(long)$_{Loc}$

'There is a moneybox. There is a straw. The straw is to the left of the moneybox.'

Signers might also use other linguistic forms to convey spatial relations between objects such as tracing, relational lexemes, pointing, lexical verb placements (see coding section and Figures 19, 20, 21 from **Chapter 2** and Figures 26, 27, 30, 31, 32 from **Chapter 3** for more details). These forms are considered to be morphologically simpler than classifier constructions (see Newport, 1989 for a discussion) because they do not incorporate morphological handshape classification of objects. Some of these forms include tracing of objects' size and shape (see Figure 20 from **Chapter 2** and Figure 31 from **Chapter 3**). Remaining strategies (i.e., relational lexemes, pointing, lexical verb placement) lack size and shape information about the objects (see also Karadöller et al., 2021 as reported in **Chapter 3**). Nevertheless, all of these linguistics forms convey iconic mapping of the spatial relation between the objects to signing space (**Chapter 2**).

One prior study found that the above-mentioned differences in iconicity across the different types of linguistic forms influenced deaf signers' visual attention prior to their linguistic descriptions of pictures containing Left-Right relations (Manhardt et al., 2020). Thus, the type of linguistic form used to encode the spatial relation in picture descriptions offers a good medium to investigate the relation between spatial language and other domains of cognition such as spatial memory. It is possible that as visual attention of signers changes prior to producing these different linguistic forms, this might then influence their subsequent memory of these relations after the linguistic production.

5.1.3. Spatial Language Use in Native versus Late Sign Language Exposure

Sign language expressions seem to help native signing children encode some spatial relations earlier than speaking children (Sümer, 2015; Sümer et al., 2014). For instance, although learning to encode Left-Right is known to be challenging for speaking children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972, Rigal, 1994, 1996), native signing children are found to encode Left-Right relations between objects earlier (around age 5) in TİD than same-aged speaking children learning Turkish (Sümer, 2015; Sümer et al., 2014). The earlier encoding of Left-Right relations by native signing children was attributed to the iconic nature of sign language encodings signed on the signing space or producing them on to the left or right side of the body (see Karadöller et al., 2021 as reported in **Chapter 3**; Sümer, 2015; Sümer et al., 2014 for TİD; Manhardt et al., 2020 for Sign Language of the Netherlands and see Figure 19 from the **Chapter 2,** and Figure 26 from **Chapter 3** for a body-anchored encoding of Left-Right in TİD).

It is less known how late exposure to language influences spatial language development. To our knowledge, only two studies investigated spatial language use in deaf children with hearing parents, who did not have immediate sign language exposure following birth (Gentner et al., 2013; Karadöller et al., 2021 as reported in **Chapter 3**). Gentner and colleagues (2013) compared spatial language use of 5-year-old deaf children before any exposure to a sign language to speaking children in a spatial language elicitation task containing descriptions of short video clips (e.g., toolbox moves on top of a school bus). Although deaf children were reported to use gestural communication systems with their parents (i.e., homesign; see Goldin-Meadow, 2013), these gestures did not have linguistic patterns used in sign languages to convey spatial information to describe the video clips. This study, however, did not investigate how linguistic strategies of these children change after short-term exposure to a sign language at the school for the deaf.

A recent study showed that after 2 years of exposure to a sign language at the school for the deaf, late signing children encoded spatial relations between objects in statistically similar frequencies to native signing children (Karadöller et al., 2021 as reported in **Chapter 3**). However, they differed from native signing children in terms of the type of linguistic forms used in these encodings when describing Left-Right relations but not In-On-Under. Specifically, late signing children used fewer classifier constructions in their descriptions and rather used other morphologically simpler forms (i.e., pointing, tracing, and lexical verb placements) more frequently than native signing children. This was attributed to Left-Right relations being cognitively challenging to acquire compared to In-On-Under. This study also showed that the effects of late sign language exposure persisted into adulthood. Late signing adults also used fewer classifier constructions than their native signing counterparts preferring other simpler forms to encode Left-Right relations albeit both groups encoded the spatial relation in statistically similar frequencies. Some other studies also presented evidence for lingering problems to use classifier constructions by late signing adolescents (Morford, 2003) and also late signing adults (Newport, 1988, 1990) who preferred morphologically simpler forms in the domain of motion event expressions.

Taken together, these studies showed that even though iconic linguistic forms that were signed on the space or on the coordinates of the body help native signing children encode spatial relations in expressing Left-Right relations earlier than their speaking counterparts (Sümer, 2015), this facilitating effect of iconicity does not provide an advantage in late sign language exposure. Late signing children and adults prefer morphologically simpler forms (e.g., pointing) compared to classifier constructions – especially when encoding cognitively challenging spatial relations such as Left-Right (Karadöller et al., 2021 as reported in **Chapter 3**). To our knowledge, there is no information on whether late sign language exposure, as well as differences in language use due to late sign language exposure in encoding Left-Right relations influence spatial memory.

5.2. The Present Study

In order to fill the gaps in the literature on the effect of late language exposure on spatial memory accuracy, we compared spatial descriptions and spatial memory of late and native signers, both in children and adults. Our first goal was to offer more robust empirical evidence on the effect of late sign language exposure on spatial language use across late and native signers by addressing limitations of prior work (Karadöller et al., 2021 as reported in **Chapter 3**). Our second goal was to investigate whether the effects of late versus early exposure extend beyond the domain of spatial language and predicted spatial memory. We also considered whether the frequency and the type of spatial language use predicted the relationship between spatial language and spatial memory given that they have been shown to differ in late exposure cases compared to early exposure and also differ in their morphological and iconic patterning.

In line with previous chapters, our empirical focus is the encoding of the cognitively complex Left-Right relations, which provides an excellent test bed as they have been found to be acquired differently by late and native signers (Karadöller et al., 2021 as reported in **Chapter 3**). The differences in linguistic forms to encode spatial relations by late and native signers might further modulate memory for spatial relations.

In our study, participants saw displays with two objects in various spatial relations to each other and were asked to describe the target picture (indicated by an arrow) to an addressee (see **Chapter 2**; Karadöller et al., 2021 as reported in **Chapter 4**; Manhardt et al., 2020, 2021 for a similar procedure). Later, we tested their recognition memory accuracy of the target pictures in a surprise recognition memory task (see Karadöller et al., 2021 as reported in **Chapter 4** for a similar procedure). We coded the spatial descriptions in terms of the frequency and the type of spatial language use and also calculated their recognition memory accuracy for the target pictures. This approach allowed us to test the relation between spatial language use and spatial memory accuracy in closely related tasks. Additionally, we measured participants' visual-spatial working memory span via the computerized version of the Corsi Block Tapping Task in forward order to ensure similarities across late and native signers.

In this study, all late signers were exposed to a sign language after age 6 and late signing children had 2 years of exposure to a sign language at the time of testing.[12] Our motivation to test after 2 years of exposure to a sign language was to replicate prior work that aimed to allow children to get enough exposure to acquire basic structures of the language as well as to ensure children have a cognitive readiness to express Left-Right spatial relations that were found to acquired late by speaking children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014).

5.2.1. Predictions

Concerning spatial language use, based on the previous work (Karadöller et al., 2021 as reported in **Chapter 3**), we predict late signers to have spatial encodings equally frequently to native signers for both children and adults. Moreover, we expect late signers, both children and adults, to use fewer morphologically complex classifier constructions compared to their native signing counterparts.

Concerning spatial memory, we investigate whether late sign language exposure, as well as the frequency and the type of spatial language use, predict spatial memory accuracy. One possibility is that these factors independently or interactively predict memory. If this is the case, we might obtain the following results:

First of all, late exposure, in general, might predict lower memory performance compared to early exposure possibly due to shorter experience with a conventional language. Specifically considering findings from children with no language exposure that showed impaired spatial memory compared to speaking children (Gentner et al. 2013), 2 years of sign language exposure might not be enough for late signing children to perform well in spatial memory tasks in comparison to native signing peers.

In addition, the type of linguistic forms used to encode the spatial relation such as encoding both the objects' shape information and the information regarding the spatial relation between the objects (as in the case of classifier constructions and tracing) might predict better spatial memory compared to

[12] All late signers (except for four adult participants) attended a primary school for deaf children. We do not have data of 4 late signing adults as they did not report whether their primary school was designed for deaf children or not.

linguistic strategies that encode only the spatial information (as in relational lexemes, pointing, and lexical verb placements).

5.3. Method

The methods reported in this study have been approved by the Ethics Review Board of the Radboud University, Nijmegen, The Netherlands and Survey and Research Commission of the Republic of Turkey Ministry of National Education, Turkey.

5.3.1. Participants

Profoundly deaf late signing children (n = 23, M_{Age} = 8;6), late signing adults (n = 23, M_{Age} = 36), native signing children (n = 21, 12 Female, M_{Age} = 8;5), and native signing adults (n = 26, 21 Female, M_{Age} = 29) of TİD participated in this study. Data from 12 additional children and 7 additional adults were excluded due to various reasons: failure to follow the instructions (n = 8), problems with the testing equipment (n = 6), and disruption during the testing sessions (n = 5). Participation was voluntary. Adult participants were given monetary compensation, child participants were given a gender-neutral color pencil kit.

All of the deaf children were recruited from the same schools and thus both late and native signing children were matched in terms of schooling experience. We compared two groups of children and adults to each other in terms of Age and Visual-Spatial Working Memory Span (i.e., Corsi Block Tapping Task) to make sure they were similar and there were no possible confounds for the measures we were interested in. We did these comparisons through Bayesian t-tests that tested for the probability of the mean difference (M_{DIFF}) greater than zero and less than zero using the R package *BayesianFirstAid* (version 0.1; Bååth, 2014). Children were similar in Visual Working Memory (Bayesian two-sample t-test: M_{DIFF} (-5) > 0: p = 0.249, M_{DIFF} (5) < 0: p = 0.751) and in Age (Bayesian two-sample t-test: M_{DIFF} (-5) > 0: p = 0.293, M_{DIFF} (5) < 0: p = 0.707). Adults were similar in Visual Working Memory (Bayesian two-sample t-test: M_{DIFF} (-5) > 0: p = 0.728, M_{DIFF} (5) < 0: p = 0.272) but not in Age (Bayesian two-sample t-test: M_{DIFF} (-5) > 0: p = 0.006, M_{DIFF} (5) < 0: p = 0.944). Late signing adults had a slightly higher mean age than their native signing counterparts.

5.3.2. Materials

5.3.2.1. Description and Familiarization Tasks

Stimuli used in the Description and Familiarization Tasks were identical to **Chapters 2 and 4** (see **Chapter 2** for details).

5.3.2.2. Memory Task

Stimuli of the Memory Task is identical to **Chapter 4.** See **Chapter 4** for the details.

5.3.3. Procedure

The procedure is identical to **Chapters 2 and 4**. Again, the experiment consisted of Familiarization Task, Description Task, Distractor Task, Surprise Memory Task, and Corsi Block Tapping Task. Please see **Chapters 2 and 4** for the details.

5.3.3.1. Familiarization Task

The procedure of the Familiarization Task was identical to **Chapters 2 and 4**. See **Chapter 2** for the details.

5.3.3.2. Description Task

The procedure of the Description Task is identical to **Chapters 2 and 4.** See **Chapter 2** for the details. Specific to the current chapter, given that all participants were deaf, both the experimenter and the addressee were signers of TİD, who had been exposed to this sign language from birth by their deaf signing parents.

5.3.3.3. Distractor Task

The procedure of the Distractor Task is identical to **Chapter 4.** Please see **Chapter 4** for the details.

5.3.3.4. Memory Task

The procedure of the Memory Task was identical to **Chapter 4.** Please see **Chapter 4** for the details.

5.3.3.5. Visual Working Memory Task

The procedure of the Visual Working Memory Task was identical to **Chapter 4.** This task was important to ensure that children and adults who had different timelines of language exposure have similar visual-spatial working memory spans (Corsi, 1972). This was especially important in looking back at studies showing mixed evidence for the differences in working memory across the late and native signers (see Marshall et al., 2015 and Emmorey, 2002).

5.3.4. Annotation and Coding: Spatial Descriptions

All sign descriptions were annotated and coded for the Target Pictures using ELAN (Version 4.9.3), a free annotation tool (http://tla.mpi.nl/tools/tla-tools/elan/) for multimedia resources developed by the Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Wittenburg et al., 2006). Data were annotated by a hearing L2 signer of TİD and coded by another hearing L2 signer of TİD. Later, annotations and coding were checked by a trained native deaf signer of TİD. We did not have a reliability coding as we only included the linguistic forms that were unambiguously approved by this native signer in the final dataset.

First of all, similar to **Chapters 2, 3, and 4**, we removed all "no attempt" trials, thus our coding is based on trials that participants attempted to describe the target picture. Further coding of the descriptions is done in two steps. Descriptions were coded first for the presence of the spatial relation between the objects and next for the linguistic form that is used to localize the Figure object with respect to the Ground object. In some of the descriptions, participants only introduced the lexical signs for the objects but not the spatial relation between them, encoded an incorrect spatial relation between the objects (e.g., rather than locating the pencil to the left of the cup, participants located the pencil to the front of the cup), or used classifier construction ambiguously due to the choice of improper handshape (e.g., using an elongated handshape to locate a round object such as a lemon). These descriptions were coded as not encoding a spatial relation. Moreover, similar to **Chapter 4**, we only considered production data of the 20 items for which we had collected the memory data.

Next, similar to **Chapters 2, 3, and 4**, we identified 5 linguistic forms that encode spatial relations in sign languages. These forms were classifier constructions (Figure 13 from **Chapter 2** and Figure 42 above from the current chapter) that were found to be the most frequent form to encode spatial relations in sign languages in general (see Emmorey, 2002) and specifically for

TİD (Karadöller et al., 2021; Sümer, 2015); tracing the Figure object's size and shape on the signing space (Figure 15; Perniss et al., 2015a); relational lexemes (Figure 19 from **Chapter 2** and Figure 26 from **Chapter 3**) that were used as the lexical signs for spatial terms in sign languages (see Arık, 2013; Karadöller et al., 2021; Sümer, 2015 for TİD; and Manhardt et al., 2020 for Sign Language of the Netherlands); pointing with index finger or palm on a specific location on the signing space to indicate the location of the Figure object (Figure 21 from **Chapter 2** and Figure 30 from **Chapter 3**; Karadöller et al., 2021); lexical verb placements (Karadöller et al., 2021; see also Newport, 1988 for the discussion of single morpheme signs; see also Figure 32 from **Chapter 3**).

For production and memory analyses, we grouped the above-mentioned forms differently. Moreover, we grouped these forms slightly differently in the current chapter than in **Chapter 3**. [13]

For production analyses, we were interested in whether the frequency of classifier constructions differed from the Other forms between native and late signers (Karadöller et al., 2021; see Table 9 from **Chapter 3** for the distribution of forms within the Other forms). That is why we grouped whether the description includes a classifier construction or any Other forms. Some of the descriptions (total 10.06% of all data; 6.40% from late 3.62% from native signers) included the use of both classifier constructions and one of the Other forms. These cases were counted only for the presence of classifier construction to avoid double counting.

For memory analyses, we grouped classifier constructions together with tracing and the remaining forms were considered as Other forms. Again, some of the descriptions (total 5.98% of all data; 2.70% from late 3.28% from native signers) included the use of both classifier constructions or tracing and one of

[13] There were two differences between coding categories for production analyses of the current chapter and **Chapter 3**. The first difference is that in the current chapter we grouped linguistic forms other than classifier construction into one category (i.e., Other Form) because none of them were frequent enough to form a single category. Yet, in **Chapter 3,** relational lexemes were not part of the Other forms and formed a single category as they were very frequently observed. The second difference between coding categories of the current chapter and **Chapter 3** is that, here, we only code one linguistic form per description, whereas in **Chapter 3** we coded multiple linguistic forms per description.

the Other forms. These cases were counted only for the presence of classifier constructions or tracing to avoid double counting. In this way, we can investigate whether linguistic forms that encode objects' shape information and spatial information (i.e., classifier constructions and tracing) predicted memory accuracy differently than that of linguistic forms that only encode spatial information (remaining Other forms).

5.4. Results

Data were analyzed using generalized binomial linear mixed-effects modeling (*glmer*) with random intercepts for Subjects and Items.[14] All models were fit with the *lme4* package (version 1.1.17; Bates et al., 2014) in R (R Core Team, 2018). This mixed-effects approach allowed us to take into account the random variability due to having different participants and different items. We did not include random slopes in any of the models because doing so did not increase the model fit.

5.4.1. Spatial Language Use

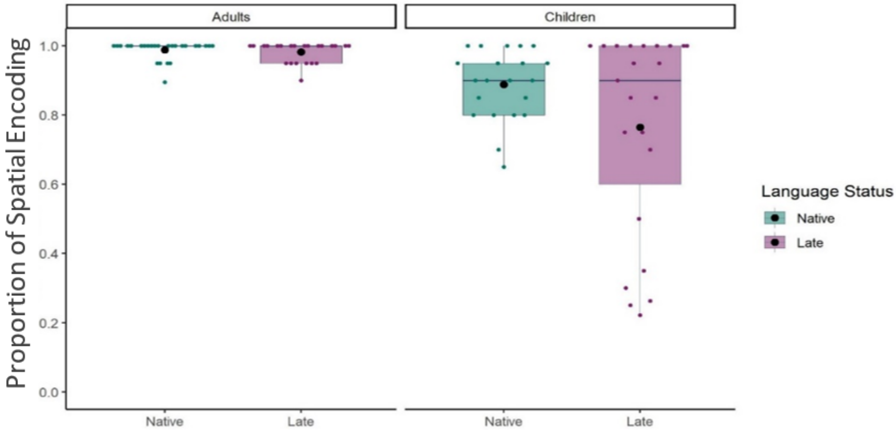
5.4.1.1. The Frequency and the Type of Spatial Encoding

First, we compared the frequency of descriptions that included spatial encoding between the objects to test whether late sign language exposure affected the amount of spatial encoding (Figure 43). We used a *glmer* model to test the fixed effects of Language Status (Native, Late), Age Group (Adults, Children), and an interaction between Language Status and Age Group on the presence of Spatial Encoding (1 = Spatial Encoding, 0 = No Spatial Encoding) at the item level. All fixed effects (Language Status and Age Group) were analyzed with centered contrasts (0.5, -0.5). The model revealed a fixed effect of Age Group ($\beta = 2.78$, $SE = 0.48$, $p < 0.01$). Adults encoded spatial relations more frequently than children. There was no effect of Language Status ($\beta = 0.29$, $SE = 0.57$, $p = 0.605$) and no interaction between Age Group and Language Status ($\beta = 0.70$, $SE = 0.97$, $p = 0.466$). That is, averaged across Age Group, late signers encoded spatial relations in statistically similar frequencies to their native signing counterparts.

[14] Display Type (Contrast, Non-contrast) was used as a fixed effect in all of the initial models, we removed it from all the models reported in this chapter as (1) it did not turn out to be significant and (2) did not improve the model fit.

Figure 43

Proportions for the presence of Spatial Encoding in relation to Language Status and Age Group.



Notes. Colored dots represent the average data for each participant. Black dots represent the mean.

Next, we focused only on the descriptions that included spatial encoding and investigated to what extent late sign language exposure influenced the type of linguistic form used to encode spatial relations between the objects (Figure 44; see also Table 12 for the distribution of linguistic forms). To do so, we compared the presence of classifier constructions across late and native signers. Here, descriptions, where classifier constructions were absent, included Other Forms (i.e., tracing, relational lexemes, pointing, lexical verb placements). We used a *glmer* model to test the fixed effects of Language Status (Native, Late), Age Group (Adults, Children), and an interaction between Language Status and Age Group on the presence of Classifier Constructions (1 = Present, 0 = Absent) at the item level. All fixed effects (Language Status and Age Group) were analyzed with centered contrasts (0.5, -0.5). The model revealed a fixed effect of Age Group (β = 2.06, *SE* = 0.49, $p < 0.001$): Adults used classifier constructions more frequently than children. There was also a fixed effect of Language Status (β = -2.19, *SE* = 0.49, $p < 0.001$): Native signers used classifier constructions more frequently than late signers. Moreover, there was an interaction between Age Group and Language Status (β = -2.35, *SE* = 0.95, p = 0.01). To follow up on the interaction effect, we used *emmeans* package (Length, 2019; Searle et al., 1980):

Table 12

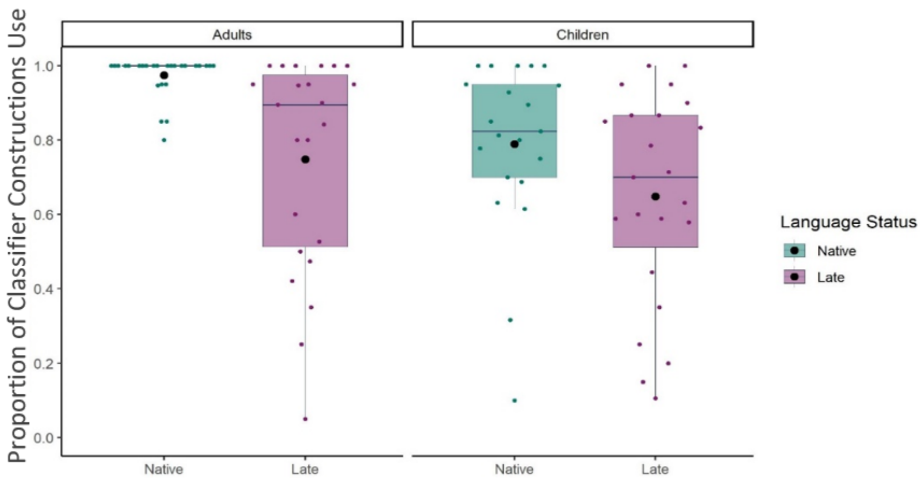
Mean proportions (and Standard Errors of the Mean) for the type of linguistic forms used when spatial relation was expressed across Language Status and Age Group.

	Classifier Constructions	Other Forms			
		Tracing	Relational Lexemes	Pointing	Lexical Verb Placements
Adults					
Native	0.87 (0.007)	0.03 (0.003)	0.07 (0.010)	0.03 (0.005)	0.00 (0.000)
Late	0.64 (0.013)	0.10 (0.010)	0.11 (0.008)	0.14 (0.010)	0.01 (0.003)
Children					
Native	0.70 (0.019)	0.11 (0.011)	0.05 (0.008)	0.10 (0.012)	0.04 (0.007)
Late	0.54 (0.018)	0.21 (0.015)	0.06 (0.010)	0.17 (0.015)	0.02 (0.004)

Separate comparisons for adults and children showed that late signing adults used classifier constructions less frequently than native signing adults (β = 3.36, *SE* = 0.76, $p < 0.01$). However, late signing children used classifier constructions in statistically similar frequencies to native signing children (β = 1.01, *SE* = 0.63, $p = 0.110$).

Figure 44

Proportions for the Presence of Classifier Constructions in relation to Language Status and Age Group.



Notes. Colored dots represent the average data for each participant. Black dots represent the mean.

5.4.2. Spatial Memory

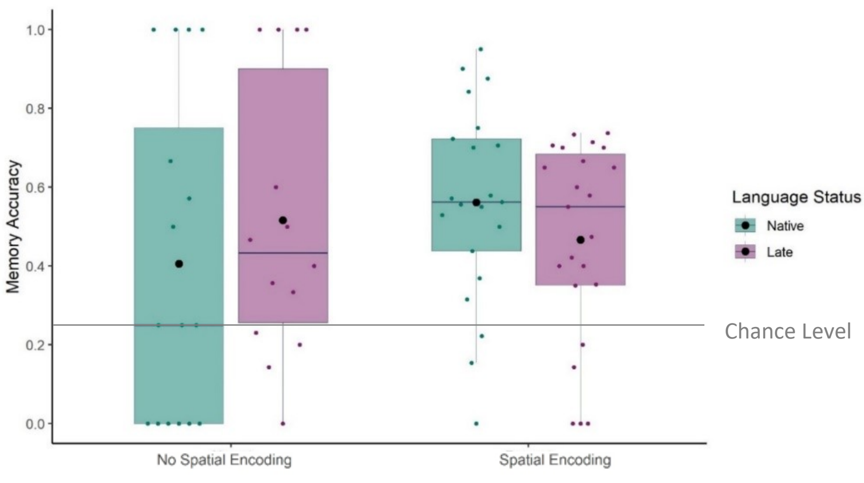
In this section, we investigated whether late versus early exposure to language on the one hand and the frequency and type of spatial language on the other or their interaction predicted memory. First, we tested whether spatial memory was predicted by the presence of spatial encoding as well as by being late versus native signer. Secondly, we tested whether spatial memory was predicted by the type of language use as well as by being late versus native signer. We conducted our models separately for children and adults in order to avoid possible confounds affecting the memory performance due to age.

5.4.2.1. Spatial Memory in Relation to Language Status and the Presence of Spatial Encoding

Here, we do not report any comparisons for adults because spatial encoding is not suitable to be used as a fixed effect since both native and late signing adults encoded the spatial relation between the objects in 99% and 98% of the cases, respectively (see **Chapter 4** for a similar strategy). For children, we investigated whether the spatial memory accuracy was predicted by the presence of spatial encoding and late sign language exposure for children (Figure 45). We used a *glmer* model to test the fixed effects of Language Status (Native, Late), Spatial Encoding (Spatial Encoding, No Spatial Encoding), and an interaction between Language Status and Spatial Encoding on the Memory Accuracy (1 = Accurate, 0 = Not accurate) at the item level. All fixed effects (Language Status and Spatial Encoding) were analyzed with centered contrasts (0.5, -0.5). There was no effect of Language Status (β = -0.29, *SE* = 0.41, *p* = 0.479), Spatial Encoding (β = -0.42, *SE* = 0.25, *p* = 0.089), and no interaction between Language Status and Spatial Encoding (β = -0.41, *SE* = 0.50, *p* = 0.403). That is, for children neither the Language Status of the participant nor the presence of spatial encoding predicted spatial memory accuracy.

Figure 45

Mean proportions of Spatial Memory Accuracy of Children in relation to Language Status and the Presence of Spatial Encoding.



Notes. Colored dots represent the average data for each participant. Black dots represent the mean.

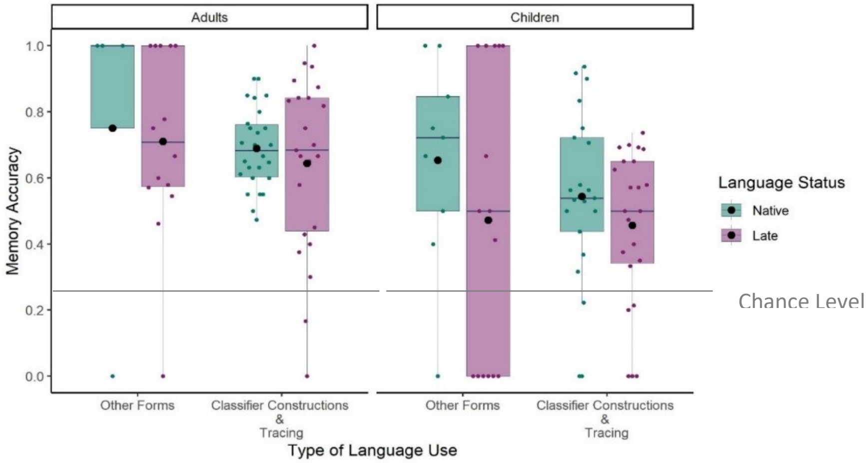
5.4.2.2. Spatial Memory in Relation to Language Status and the Type of Language Use

Next, we focused only on the descriptions that include spatial encoding and investigated to what extent spatial memory was modulated by the type of language use and late sign language acquisition tested separately for children and adults (Figure 46). For the Type of Language Use. we compared linguistic forms that encode both the objects' shape information and spatial relation between the objects (i.e., classifier constructions and tracing) to forms that only encode spatial relation between the objects (relational lexemes, pointing, and lexical verb placements) to see if different types of linguistic forms predicted spatial memory.

We used separate *glmer* models for adults and children to test the fixed effects of Language Status (Native, Late), the Type of Language Use (Classifier Construction and Tracing, Other Forms), and the interaction between Language Status and the Type of Language Use on the presence of Memory Accuracy (1 = Accurate, 0 = Not accurate) at the item level. All fixed effects (Language Status and the Type of Language Use) were analyzed with centered contrasts (0.5, -0.5). There was no effect of Language Status (*Adults:* β = -0.75, *SE* = 0.60, p = 0.208; *Children:* β = -0.62, *SE* = 0.43, p = 0.154), Type of Language Use (*Adults:* β = -0.65, *SE* = 0.57, p = 0.253; *Children:* β = -0.39, *SE* = 0.32, p = 0.233), and no interaction between Language Status and the Type of Language Use (*Adults:* β = 1.49, *SE* = 1.14, p = 0.190; *Children:* β = 0.45, *SE* = 0.64, p = 0.487). That is, for both adults and children, neither the Language Status of the participant nor the Type of Language use predicted Spatial Memory Accuracy.

Figure 46

Mean proportions Memory Accuracy in relation to Language Status, Type of Language Use, and Age Group.



Notes. Colored dots represent the average data for each participant. Black dots represent the mean.

5.5. Discussion

In this study, we aimed to provide evidence for the relation between spatial language and memory and asked whether and how late or early language exposure predicts the relation between spatial language use and spatial memory in deaf signing children and adults by also taking into account the linguistic productions of both language exposure groups. Going beyond previous work (Karadöller et al., 2021 as reported in **Chapter 3**), first, we tested whether the effects of late language exposure on the frequency and the type of spatial language use in encoding Left-Right relations obtained for children and adults were replicable using a more balanced stimuli set and larger sample while controlling for general cognitive skills across the groups. Secondly, we investigated whether late sign language exposure and also the possible differences in the frequency and the type of spatial language use predicted the relationship between spatial language and memory or not.

Concerning spatial language use, our results showed that late language exposure did not affect the frequency of spatial language use both between late and native signing children and late and native signing adults. However, late language exposure affected the type of spatial language use where late signers used fewer classifier constructions compared to native signers. This was also modulated by age group. That is, late signing adults used fewer classifier constructions than native signing adults whereas late and native signing children used classifier constructions in statistically similar frequencies. Moreover, overall adults encoded the spatial relation between the objects more frequently and used classifier constructions more frequently than children. Finally, we found that neither late language exposure nor the frequency and the type of language use or their interaction predicted memory accuracy.

5.5.1. Effects of Late Sign Language Exposure on the Frequency and the Type of Spatial Language Use

Our results were mostly in line with the previous findings for the effects of late sign language exposure on the frequency and the type of spatial language use, replicating Karadöller et al. (2021; as reported in **Chapter 3**), except for the use of classifier constructions for children. Similar to Karadöller et al. (2021; as reported in **Chapter 3**), we found that, after 2 years of sign language exposure, late signing children could encode spatial relation between the objects in statistically similar frequencies to their native signing peers and this effect persisted into adulthood. This is an important finding considering that deaf children with no language exposure lacked any gestures to communicate spatial information before they started the school for the deaf (Gentner et al., 2013). Here, our findings have the potencial to extend the literature on the spatial language development of deaf children with hearing parents by demonstrating that having a short-term exposure to language could scaffold the development of linguistic encoding of space very fast. This indicates that possible linguistic forms mapped onto an independently developed conceptual understanding of spatial relations. Nevertheless, this interpretation should be taken cautiosly as we did not test the very same children tested in Gentner et al. (2013) and used a completly different stimuli and procedure.

Moreover, similar to previous work (Karadöller et al., 2021 as reported in **Chapter 3**), we found that adults encoded spatial relations more frequently than children regardless of language exposure. This shows that even by age 8, neither native nor late-signing children are adult-like in the frequency of descriptions that encode Left-Right relations. With this finding, we contribute to claims pointing to the challenge of spatial domain in linguistic development specifically for Left-Right – albeit they are learned earlier by signing than speaking children (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 194, 1996; Sümer, 2015; Sümer et al., 2014).

Secondly, with regard to the type of spatial language use, we found that late signing adults used classifier constructions less than their native signing counterparts, however, late signing children used classifier constructions in statistically similar frequencies to their native signing peers. This is unlike prior work showing that both late signing children and adults used classifier constructions less frequently than their native signing counterparts (Karadöller et al., 2021 as reported in **Chapter 3**). Considering that the current study incorporated more stimuli materials that were controlled in many aspects, as well as more participants who were matched in several criteria such as general cognitive abilities, we believe it may better represent the effect of late sign language acquisition on spatial language use.

That is, the effect of late sign language exposure may be more salient for adults than for children. This could be partially due to the fact that native signing children are also not adult-like in encoding Left-Right relations and thus differences between late and native signing children are less visible. This provides more evidence to the claim that the effect of late sign language exposure is more strongly observed as signers get older (see Morford, 2003; Newport 1988, 1990). Overall, the low frequency of classifier constructions used by late-signing adults compared to their native signing counterparts might point out a general linguistic challenge for late signers to acquire morphologically complex forms (see Newport, 1990) especially in encoding Left-Right relations despite their iconicity (Karadöller et al., 2021 as reported in **Chapter 3**). Thus, facilitating effect of iconicity of the linguistic forms could only be observed in early exposure cases.

5.5.2. Relation between Spatial Language Use and Spatial Memory Accuracy

Our study showed late sign language exposure did not predict spatial memory performance neither for children nor for adults. Furthermore, we found that neither the frequency nor the type of spatial language use predicted spatial memory accuracy. We also did not detect any interaction between late sign language exposure and the frequency or the type of spatial language use.

Specifically, for the type of spatial language use, we could have expected to see linguistic forms that encode both the objects' shape information and the spatial relation to predict better memory compared to linguistic forms that only encode spatial information. This was based on previous research showing that encoding both the objects' shape information and the spatial relation between the objects recruited visual attention differently than that of linguistic forms that only encoded the spatial relation between the objects (Manhardt et al., 2020). This result may suggest that the influence of spatial language on cognitive processes may emerge during language use such as in visual attention while planning linguistic descriptions, but such an effect may not always last after language use is completed.

It is also possible that our paradigm could not detect the differences in spatial memory. For example, not imposing participants to respond quickly in the memory task might have diminished the differences in memory accuracy, in which participants took their time to find the correct answer. Moreover, it is also possible that having used pictures as the stimuli material (*picture superiority effect*; Paivio et al., 1968) coupled with asking participants to describe the target pictures during encoding (*production effect*; Conway & Gathercole, 1987) might have boosted memory accuracy (see Zormpa et al., 2019 for the complex interplay between picture superiority and production effects in psycholinguistics research) and washed out the possible effects. Moreover, due to the nature of our design, we were constrained by the production patterns produced naturally by the participants. For instance, encoding spatial relation between obhects resulted in ceiling performances for the adult groups and there were considerable individual variation in production patterns of late signing children. Results should be interpreted with caution to avoid sweeping generalizations for the relationship between spatial langauge use and spatial memory.

Therefore, our findings, in general, do not support previous findings showing a relation between spatial language use and later memory accuracy (Abarbanell & Li, 2021; Cassasola et al., 2020; Dessalegn & Landau, 2008; Gentner, et al., 2013; Hermer-Vasquez et al., 2001; Loewenstein & Gentner, 2005; Miller et al., 2016; Pruden, et al., 2011; Shusterman et al., 2011; Simms & Gentner, 2019) in native and late signing children. Therefore, findings in the current chapter also differ from that of findings in **Chapter 4** (Karadöller et al., 2021) that has shown a relation between encoding the spatial relation in language and subsequent memory for spatial relations for signing and speaking children compared to not encoding the spatial relation in language. We will discuss possible factors for the difference between **Chapter 4** and **Chapter 5** in the general discussion section (**Chapter 6**) of the current thesis. It should also be noted that we report the relationship between spatial language use and spatial memory accuracy only for two spatial relations, that is left-right, and results may not be generalizable to other spatial relations.

Finally, in order to provide a complete picture of linguistic and cognitive development of space in late sign language exposure cases, further research should concentrate on testing the same children before and after language exposure and comparing them to native signing children to definitely uncover the effects of language on memory.

5.6. Conclusion

Here, we showed that late exposure to language influences the frequency and the type of spatial language use for encoding Left-Right relations, but it does not necessarily predict the relation between spatial language and memory – even when the frequency and the type of language use are taken into account (Gentner et al., 2013; Hyde et al., 2011; Karadöller et al., 2021 as reported in **Chapter 3**). Even though late exposure affects the use of morphologically complex forms to encode spatial relations (e.g., classifier constructions), albeit more visible in adults than children, this does not, in turn, predict memory performance even when the level of iconicity in the linguistic forms are taken into account.

Chapter 6: General Discussion and Conclusion

The main goal of the current thesis was to investigate how children develop the ability to communicate and reason about space and which factors influence the development of this ability. As laid out in the general introduction, the development of spatial language is considered to be determined by an interaction of cognitive and linguistic factors. Thus far, the interplay of these factors has been studied exclusively by focusing on the linguistic variation across different spoken languages and focusing on hearing children who are exposed to language from birth. The current thesis investigated the role of variation in language modality such as in speech, gesture, and sign as well as the role of variation in the timing of language exposure as in late versus early exposure to sign language as novel perspectives to enhance our understanding of the relation between linguistic and cognitive factors influencing spatial language development. It also investigated whether such variations in spatial language use predict subsequent memory for spatial relations.

In investigating the influence of variation in language modality on spatial language development, the current thesis did not only compare sign to speech but also took speakers' co-speech gestures into account. Doing so revealed new insights into how iconic forms of spatial expressions inform our understanding of spatial language development. That is, spatial language development can be influenced by linguistic factors in addition to cognitive ones. Furthermore, in investigating the influence of variation in the timing of language exposure, the current thesis compared data from child and adult signers who were exposed to sign language late or from birth. This investigation helped uncover to what extent spatial language development depends on early language input or can map onto cognitive understanding of space. Finally, the current thesis examined whether these variations influence the relationship between spatial language use and its relations to subsequent spatial memory performance.

The core research questions that have guided the research conducted in **Chapters 2 to 5**, are the following:

*(RQ1) Does the variation in language modality as in speech, sign, and co-speech gestures modulate how children use spatial language (**Chapter 2**)?*

(RQ2) *Does the variation in the timing of language exposure modulate using spatial language in the case of deaf late and native signers (**Chapter 3**)?*

(RQ3) *Do modality of language use (investigated in RQ1) and the timing of language exposure (investigated in RQ2) influence subsequent memory for spatial relations?*

(RQ3a) Does modality of linguistic encoding predict memory for spatial relations (**Chapter 4**)?

(RQ3b) *Does late sign language exposure, as well as the differences in spatial language use due to late sign language exposure, predict memory for spatial relations (**Chapter 5**)?*

To answer these questions, data were collected from deaf children and adults using TİD and hearing children and adults using Turkish. This approach provided novel insights from cross-linguistic and multimodal perspectives to previous research. The specific domain of space was locative spatial relations (e.g., *the pen is to the left of the paper*) for two reasons: First, this is a domain that most of the previous work has been carried out including Turkish and TİD and allowed us to build on previous literature more directly. Second, learning to encode Left-Right is known to be cognitively challenging for children enabling us to investigate the interactions between linguistic and cognitive factors shaping the development of spatial language.

In the remainder of this chapter, there is an overview of the main findings of the preceding experimental chapters (**Chapters 2 to 5**). This overview is followed by a discussion of these findings for their theoretical implications within a broader literature on the development of spatial language and the relationship between spatial language, spatial cognition, and spatial memory. The final sections state the methodological contributions, directions for future research, and societal implications of the findings.

6.1. Summary of the main findings

The first main research question of the current thesis (RQ1) was to what extent modality differences in language modulate the development of spatial language beyond what can be determined by cognitive development. **Chapter 2** explored this question from the perspective of informativeness, which has been operationalized as whether the participants' linguistic encodings uniquely distinguish the spatial relation between objects in a target picture among spatial relations depicted in other pictures in a display. This chapter tested whether the difficulty of encoding Left-Right relations is present regardless of the modality of expression or is modulated by using iconic ways to encode space (i.e., sign and co-speech gestures) compared to using arbitrary forms as in speech. We predicted that iconic affordances of sign and gesture would facilitate the informativeness of spatial descriptions. Indeed, we showed that signers were more informative than speakers for all age groups when sign was compared to speech. When co-speech gestures were considered on top of speech, the use of co-speech gestures was expected to increase the informativeness of expressions, and thus speakers were expected to be equally informative to signers. As expected, results showed that the use of co-speech gestures increased the informativeness of expressions in speaking children compared to encodings to speech. Later, when sign was compared to speech-gesture combinations, signing children were still more informative than their speaking peers, whereas signing and speaking adults were equally informative to each other. Furthermore, for the comparisons across adults and children in each modality (i.e., speech, sign, speech-gesture combinations), we predicted that learning to encode Left-Right relations would be challenging for children. Indeed, we found that regardless of the modality of expression children were less informative than their adult counterparts when expressions in all modalities were accounted for.

The second research question (RQ2) was whether the variation in the timing of sign language exposure, as in deaf late and native signers, modulates the development of spatial language use. **Chapter 3** investigated this question to explore the relationship between linguistic and cognitive factors shaping spatial language development. Here, we focused on two types of spatial relations that vary in their cognitive complexity. The first one was viewpoint-independent relations (In-On-Under) that are known to be simpler and acquired earlier. The second one was viewpoint-dependent relations (Left-Right) that are known to be complex and acquired later. First, we predicted that if cognitive development plays a major driving role in the development of spatial language, late signers would be encoding spatial relations as frequently as their native signing counterparts despite the absence of language exposure in the first 6 years of life. As expected, the results of **Chapter 3** showed that late sign language exposure did not affect the frequency of spatial encodings by late signers compared to native signers. Thus, after 2 years of exposure to a sign language, late signing children could already express the spatial relation between the objects in statistically similar frequencies to their native signing peers. With regard to the type of spatial relation (i.e., viewpoint-dependent versus viewpoint-independent), we predicted three possibilities that would reveal relations between cognitive and linguistic factors in determining spatial language development. First, it was possible to observe the role of cognitive factors playing a driving role for the development of spatial language such that viewpoint-independent relations would be learned earlier than viewpoint-dependent relations by late as well as native signers. Second, it was possible to observe the role of linguistic factors playing a driving role in the development of spatial language such that late signers would use morphologically complex forms less frequently than native signers. Thirdly, it was possible to observe an interaction between cognitive and linguistic factors in shaping spatial language development. That is, late exposure could hinder the acquisition of morphologically complex linguistic structures only when encoding cognitively complex spatial relations (i.e., viewpoint-dependent) but not cognitively simpler ones (i.e., viewpoint-independent). Consistent with our last prediction, results revealed an interaction between linguistic and cognitive factors. That is, morphologically complex forms (i.e., classifier constructions) were more susceptible to the effects of late sign language exposure than morphologically simpler forms (i.e., pointing) when encoding viewpoint-dependent relations but not when encoding viewpoint-independent relations. We also found a general age effect regardless of the time of language exposure. That is, children used morphologically simpler forms more than adults.

The third research question (RQ3) asked whether variations in language modality and timing of language exposure predict the relationship between spatial language use and subsequent spatial memory. The first part of the third question (RQ3a), investigated in **Chapter 4,** was about whether encoding a spatial relation in a picture description predicts later recognition memory accuracy for native signers and speakers and whether differences in the modality of enc*oding ("speech alone versus speech-plus-gesture*", "*speech alone versus sign*" or "*sign versus speech-plus-gesture*") further predict differences in spatial memory. Based on previous work showing a strong relation between spatial language use and memory, we expected that encoding spatial relations with language would predict better memory accuracy. We also expected encoding spatial relations through visual-spatial forms to modulate this relationship. Consistent with our first expectation, our results showed that encoding the spatial relation in the picture description predicted higher recognition memory accuracy than not encoding a spatial relation for children. Note that **Chapter 4** did not report findings concerning the spatial encoding for adults as adult data did not show a variation for spatial encoding. Nevertheless, contrary to our second expectation, the modality of the description encoding the spatial information did not predict differences in memory accuracy for adults or for children.

Finally, the second part of the third question (RQ3b), investigated in **Chapter 5**, was about whether late sign language exposure, as well as the differences in spatial language use due to late sign language exposure, predict spatial memory accuracy. Before testing the relation between spatial language and memory, we first attempted to replicate the effects of late sign language exposure on the language production obtained in **Chapter 3** by using more stimuli materials that were controlled in many respects and a larger sample that was matched in several aspects. To do so, we zoomed into the viewpoint-dependent relations (i.e., Left-Right) because late sign language exposure has been found to affect the spatial language use only for viewpoint-dependent relations. Similar to **Chapter 3**, we predicted that late sign language exposure would not affect the frequency of encoding the spatial relation but would affect the type of linguistic form used to encode the spatial relation. Results, indeed, showed that the effects of late sign language exposure on spatial language use were mostly in line with **Chapter 3**. That is, late sign language exposure did not affect the frequency of encoding the spatial relation across late and native signers. Moreover, results showed that late signing children could encode spatial relations as frequently as their signing peers after a short-term exposure to language despite the absence of language input in the first 6 years of life. However, late exposure affected the type of spatial language use. That is, late signers used morphologically complex linguistic forms (e.g., classifier constructions) less frequently than their native signing counterparts. However, unlike in **Chapter 3**, this effect was modulated by the age of the participants. That is, late signing adults used fewer classifier constructions than native signing adults whereas late and native signing children used classifier constructions in statistically similar frequencies. Furthermore, both late and native signing children differed from their adult counterparts in their frequency and type of spatial language use. That is, children encoded Left-Right relations less frequently and used morphologically complex forms less frequently than adults. Next, for the relationship between spatial language and memory, we predicted that linguistic encoding of spatial relations would promote better memory performance than not encoding the spatial relation. We also expected that encoding the spatial relation through different types of linguistic forms (linguistic forms with more iconic features such as encoding size and shape of the objects in addition to encoding spatial relation between the objects or only encoding the spatial relation between the objects) might further modulate memory. Contrary to our expectations, and unlike in **Chapter 4**, encoding the spatial relation in language did not predict memory accuracy for children (note that similar to **Chapter 4, Chapter 5** did not report findings concerning the spatial encoding for adults as adult data did not show a variation for spatial encoding). Moreover, encoding the spatial relation through different linguistic forms did not modulate the relationship between spatial language use and subsequent memory for spatial relations.

6.2. Discussion

All the chapters summarized above show that variation in language modality and timing of sign language exposure *do* modulate the development of spatial language particularly regarding linguistic encoding of Left-Right relations. Nevertheless, these variations *do not* have effects beyond spatial language use and thus *do not necessarily* modulate the relationship between spatial language use and subsequent memory for spatial relations. Rather, results showed that whether or not spatial language has been used in a description predicts spatial memory to some extent (in **Chapter 4** but not in **Chapter 5**). Possible theoretical and methodological factors pertaining to the results will be discussed below.

6.2.1. Theoretical Contributions of the Current Thesis in Investigating the Spatial Language Use and Its Relations to Spatial Memory

6.2.1.1 Mutual Interplay between Linguistic and Cognitive Factors on Development of Spatial Language

Language production results reported in **Chapters 2, 3, and 5** show that the development of spatial language is the outcome of an intricate interaction between language-specific ways to encode spatial relations, on the one hand, and nonlinguistic cognitive understanding of spatial relations, on the other. More specifically, these results revealed the contributions of iconicity and morphological complexity of linguistic expressions and order of cognitive development of space on development of spatial language use.

6.2.1.1.1. Linguistic Factors Influencing Development of Spatial Language. The current thesis shows converging evidence for how language-specific ways to encode spatial relations play a driving role in shaping development of spatial language use. **Chapters 2, 3, and 5** show evidence first of all that iconicity of the linguistic forms facilitates learning to encode spatial relations compared to speech (**Chapters 2**) and even in the case of late sign language exposure (**Chapters 3 and 5**). Moreover, **Chapters 3 and 5** further show that morphological complexity of the linguistic forms in sign influences the development of spatial language in signing children in general as well as in late signers in particular.

Effects of Iconicity*:* The first piece of evidence for facilitating effect of iconicity comes from findings comparing sign to speech when encoding Left-Right relations. **Chapter 2** has shown that sign has an advantage over speech both for adults and children. The facilitating effect of sign over speech coheres with previous findings with adults showing iconic affordances of manual modality in sign enhancing communicative efficiency and informativeness (e.g., Slonimska et al., 2020) and to a greater extent than speech (Taub, 2001; Taub & Galvan, 2001). The present findings extend this literature to children and to the domain of space. For children, they corroborate earlier findings from Sümer et al. (2014) that signing children benefit from iconic linguistic forms that directly map spatial relation between the objects in the real space onto the signing space or on the coordinates of their body in encoding Left-Right relations. Possibly, speaking children are relatively disadvantaged in encoding Left-Right relations due to having to encode space with arbitrary linguistic forms in speech that do not have an iconic link to their meaning. Moreover, the present findings also show the robustness of this effect going beyond Sümer et al. (2014) by providing data from a larger sample of participants and a higher number of stimuli materials. Our findings also show, together with Sümer et al. (2014), that morphological complexity of the linguistic forms to encode space in sign languages is not delaying the acquisition of spatial language of signers compared to speakers as argued by previous research for the descriptions of motion events (e.g., Kantor, 1980; Newport & Meier, 1985; Schick, 1990; Supalla, 1982; Slobin et al., 2003 for American Sign Language; Engberg-Pedersen, 2003 for Danish Sign Language; Tang et al., 2007 for Hong Kong Sign Language). When considering locative relations that are semantically simpler than motion events (Talmy, 1985), iconicity of the sign language structures facilitates spatial language use compared to speech. Therefore, sign advantage is less likely to be due to possible differences in morphological complexity of the ways to encode space that might differ between spoken and signed languages but more likely due to the facilitating effect of iconicity of the spatial description. It is also important to note that sign advantage shown in the present results is obtained when comparing a sign (i.e., TİD) and a spoken language (i.e., Turkish) that both encode space in morphologically complex ways (see Johnston & Slobin (1979) for Turkish in comparison to other languages such as English).

The second piece of evidence for facilitating effect of iconicity comes from findings comparing sign to speech-gesture combinations when encoding Left-Right relations. **Chapter 2** went beyond the previous comparison between sign and speech in showing the influence of iconicity and also compared sign to multimodal expressions of speaking children by taking gestures into account. Here, it was found as a novel finding that sign advantage persisted in childhood but disappeared in adulthood. This shows that even though both gestures and sign facilitate the informativeness of a spatial description over speech, description in sign seems to be more informative than descriptions in speech-plus-gesture for children but not for adults. This can be attributed to having visual modes of expressions as conventional linguistic strategies in sign languages (Brentari, 2010; Emmorey, 2002; Klima & Bellugi, 1979; Stokoe, 1960) showing stronger evidence for the role of language-specific factors in shaping spatial language development. Gestures, on the other hand, have fewer and non-obligatory ways for iconic encoding. Furthermore, they only form a composite system together with speech rather than forming a system only by themselves (Kendon, 2004; McNeill, 1992, 2005; see Perniss et al., 2015b for a discussion). This could, in turn, have resulted in a higher impact of linguistic factors in shaping the development of spatial language for signing children than speaking children even when their gestures are taken into account.

The third piece of evidence for the facilitating effect of iconicity comes from speaking children's affinity to recruit spatial gestures more than adults when their speech fails to convey uniquely referring information to encode spatial relations. **Chapter 2** showed that gestures act as a medium to encode spatial relations and they can encode more spatial information than what was encoded in speech. This finding implies that children have some cognitive understanding of Left-Right spatial relations between objects around age 8. Even though this understanding was not expressed in speech, children could express it through co-speech gestures. This explanation is in line with the literature suggesting that gestures precede speech in several other domains of development (e.g., Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry et al., 1988). Present findings extend this literature to the domain of space and to contexts where gestures are not prompted (e.g., Sauter et al., 2012) but used spontaneously by children themselves. This finding also adds evidence to theories positing that cognition is deeply rooted in body's interaction with the world (*embodied cognition*; e.g., Chu & Kita, 2008; Goldin-Meadow, 2016). It is possible that children can more easily map iconic gestures on their embodied representation of spatial relations between the objects than speech. As in almost all descriptions, children describe the spatial relation between the items from their own perspective and in doing so it is highly possible that children mentally aligned the location of the objects that they saw on the computer screen with the left and right sides of their own body. Moreover, these results can be explained with the view that gestures activate, manipulate, package, and explore spatio-motoric information for the purposes of speaking and thinking (i.e., *Gesture for Conceptualization Hypothesis;* Kita et al., 2017). Several studies suggested that these processes might help children find ways to incorporate missing information in speech while describing Left-Right spatial relations and children may be using gestures as an index of conceptualization. Yet, our study was not set to disentangle cognitive processes behind using spatial gestures. We believe these are very important questions for further research.

The fourth piece of evidence for facilitating effect of iconicity for spatial language, albeit not as definitive as other pieces of evidence, comes from late exposure findings. We demonstrated that having a short-term exposure to sign language could help with the development of linguistic encoding of space (**Chapters 3 and 5**). A possible interpretation of this could be that late signing children might have benefited from iconic affordances of sign language expressions of space and thus map linguistic forms in sign to spatial relations in the outside world even after 2 years of exposure. This possibility is plausible especially when considering previous research with Turkish deaf home signing children showing that their gestural descriptions do not convey spatial relations prior to sign language exposure (Gentner et al., 2013). However, since the current thesis did not test acquisition of iconic versus non-iconic forms in late sign language exposure, we cannot definitely claim that iconicity of the linguistic forms facilitated the spatial language development of late signing children. We acknowledge that this is a very important area of future research. Finally, it is still possible to interpret this finding providing evidence that cognitive understanding of space might develop even in the absence of language input for the first 6 years of life. We discuss this last possibility in more detail in the below section (6.2.1.1.2.).

Effects of Morphological Complexity: In addition to the iconicity of the linguistic forms, morphological complexity of the linguistic forms to encode spatial relations in sign provides evidence for linguistic factors shaping the development of spatial language (**Chapters 3 and 5**).

The first piece of evidence showing the role of morphological factors is that late signers use morphologically complex forms less frequently than their native signing counterparts in encoding Left-Right relations between objects (note that in **Chapter 5** this finding is only present for adults but not for children). For adults, this finding echoes previously reported results showing that late sign language exposure hinders linguistic abilities in general (e.g., Boudrelaut & Mayberry, 2006; Mayberry, 1993) and spatial language use in particular (Newport, 1988, 1990). Specifically for spatial language use, late signing adults have been found to use morphologically complex verbs of motion less frequently in describing motion events (Newport, 1988, 1990). That is, in encoding motion events, late signing adults use linguistic expressions that require morphologically complex verbs of motion (e.g., the sign for FALL consists of downward V handshape that is the classifier handshape for human + moved along an arc which is a path morpheme + a manner morpheme) less frequently. Rather, they prefer monomorphemic signs (e.g., OUT) (Newport, 1988). Similarly, late signing adolescents have been shown to replace monomorphemic signs with verbs of motion gradually during 3 years of exposure with sign language (Morford, 2008). Thus, the present findings add to the literature by showing that the morphological complexity of the linguistic structures to encode space in sign languages plays an important role in shaping spatial language development also with locative expressions. Nevertheless, we also found that the morphological complexity of the linguistic forms impacts learning to encode spatial relations for cognitively complex spatial relations (i.e., Left-Right) but not cognitively simpler ones (i.e., In-On-Under) (**Chapter 3**). This suggests an interplay between cognitive and morphological factors in determining spatial language development. Finally, it is worth pointing out that, in **Chapter 5,** we did not find effects of late exposure on morphological complexity for children but found it only for adults. Possibly, as native signing children also used morphologically complex constructions for Left-Right relations less frequently compared to native signing adults, the difference between late and native signers surfaced only in adulthood. This also points to the modulating effect of morphological complexity on the development of spatial language for signers.

It is important to note that linguistic differences that have arisen due to late exposure to language can be attributed to the sociolinguistic differences in language input situations of late signers compared to native signers over the years. One of the major differences is that late signers are not born into a signing community. Rather they are surrounded by speakers who communicate with them mainly through gestures (i.e., homesigns; Goldin-Meadow, 2013). These gestures consist of pointing signs and gestures that represent actions, objects, or attributes (see Lillo-Martin & Henner, 2021). Thus, late signers only get exposed to a conventional sign language in the school environment. Yet, this exposure is also often far from optimal as late signing children are exposed to a sign language only during recess from their signing peers most of whom are also late signers (see Mitchell & Karchmer, 2004). Therefore, these differences in language input situations might have resulted in determining the linguistic differences between late and native signers over the years when they reach adulthood. Thus, the reason why late signers prefer morphologically simpler forms over morphologically complex ones might be the result of their exposure to simpler structures in communication (e.g., points to space) more frequently while communicating with speakers and/or with other late signing peers. Further research should investigate interactional patterns between deaf signing peers in school contexts.

The last piece of evidence for how morphological factors shape spatial language development comes from signing children's preference for simpler forms (e.g., pointing) more than their adult counterparts regardless of the timing of sign language exposure (**Chapters 3 and 5**). The higher frequency of simpler forms by late and native signing children compared to adults gives insight into the developmental trajectory of learning to encode spatial relations. These forms, particularly pointing, are considered as the foundational *building blocks* of the human communication as Kita (2003) suggests. This is especially plausible for sign languages that use pointing for numerous grammatical functions (Wilbur, 1987). Even before taking part in the fully functioning grammatical constructions in sign languages, points to space have been shown to be recruited in the earlier communication of deaf individuals. For instance, points have been shown to be an integral part of the communication of homesigners to refer people's locations on space (Coppola & So, 2005) and have been shown to be employed by late signing children frequently to indicate locations of objects with respect to each other (Karadöller et al., 2021 as reported in **Chapter 3;** also see **Chapter 5**). In addition, pointing has been observed as one of the gestural strategies in speaking children's spatial encodings as well (see **Chapter 2** for more details). Hence, pointing seems to provide a gateway to spatial language in ways speech cannot. Finally, pointing seems to act as a preferred morphologically simple strategy in learning to encode space for signers. It could also be preferred by speakers due to its simplicity. Yet, in **Chapter2**, we did not look into different gestural strategies to uncover whether children prefer pointing over iconic hand placement gestures and thus cannot provide evidence for this claim.

Overall, considering all the above-mentioned findings, the current thesis adds to previous views arguing that linguistic factors (i.e., iconicity, morphological complexity, and the primacy of pointing) play an important role in shaping spatial language development for speaking as well as late and native signing children. These contribute to previous findings on modulating effects of language-specific factors (e.g., semantic specificity, lexicalization, and syntactic patterns) modulating spatial language development in spoken language expressions across languages (e.g., Allen et al., 2008; Bowerman, 1996a, 1996b; Bowerman & Choi, 2011; Choi & Bowerman, 1991; Johnston & Slobin, 1979; Özçalışkan & Slobin, 2000).

6.2.1.1.2. Cognitive Factors Influencing the Spatial Language Development. The current thesis also shows evidence for cognitive factors playing an important role in shaping spatial language development. Evidence for this comes from findings showing that the linguistic development of spatial relations reflects the order of cognitive development of space regardless of modality of encoding (**Chapter 2**) and timing of language exposure (**Chapters 3 and 5**).

First of all, one of the most robust findings of the current thesis is that Left-Right is a challenging domain for 8-year-old children. This finding is not only obtained when comparing signing and speaking children to their adult counterparts regardless of modality of encoding; that is in sign, speech, and speech-plus-gesture (**Chapter 2**) but also obtained when comparing late and native signing children to their adult counterparts (**Chapter 5**). These results are important as they provide additional evidence to the claims that Left-Right is a difficult domain for speaking children (Abarbanell & Li, 2021; Clark, 1973; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). Moreover, these results extend this literature by providing more evidence that this effect can be obtained regardless of the language modality (i.e., speech, sign, and speech-gesture combinations) or timing of language exposure. Therefore, encoding Left-Right spatial relations is not only challenging due to the need for learning to encode space via arbitrary ways by speaking children but also constitutes a universal challenge (**Chapter 2**). In addition, being exposed to sign language late or from birth does not change the course of this effect, as we found both native and native signing children to encode Left-Right relations less frequently than their adult counterparts (**Chapter 5**).

The second evidence for how cognitive factors influence the development of spatial language comes from late signers. We hypothesized that if cognitive development is shaped by language to a great extent, late signing children might have lagged behind their native signing peers in learning to encode spatial relations. Alternatively, if cognitive development can develop independent of language at least in the first 6 years of life without language input, late signers might have comparable performance to their native signing peers in encoding spatial relations. Having observed that late signing children could encode the spatial relations equally frequently and through linguistically similar ways to their native signing peers (**Chapters 3 and 5**), we suggest cognitive understanding of spatial relations may develop to some extent in the absence of conventional language input. Therefore, upon short-term exposure to language, late signing children can learn to map linguistic forms in sign to their already developed concepts and relatively quickly. Yet, we acknowledge that based on our design it is impossible to clearly understand how cognitive understanding of spatial relations develops before and after language exposure. Future research should consider observing deaf children both before and after language exposure and always in comparison to their native signing peers to better understand the role of cognitive understanding of spatial relations on the development of spatial language in late sign language exposure. Moreover, we also acknowledge that these children are exposed to a language that is iconic, which might have facilitated their acquisition upon short-term exposure as discussed above.

Finally, another piece of evidence for the cognitive factors playing a role in spatial language development comes from our finding in **Chapter 3** that late signers differed from native signers in encoding viewpoint-dependent but not viewpoint-independent relations. This finding corroborates claims about order of cognitive understanding of space playing a role in spatial language development (e.g., Clark, 1973; Johnston, 1985). Consistent with the earlier literature we showed evidence for primacy of linguistic development of viewpoint-independent relations (e.g., Clark, 1973; Johnston & Slobin, 1979;

Tomasello, 1987; Sümer, 2015) and a challenge in encoding viewpoint-dependent relations, especially Left-Right (e.g., Abarbanell & Li, 2021; Clark, 1973; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014). Extending the previous literature, we showed these effects first time for late sign language exposure cases. Therefore, it seems that viewpoint-independent relations that are simpler and acquired earlier are less susceptible to the effects of late sign language exposure. However, viewpoint-dependent relations that are complex and acquired later are more susceptible to the effects of late sign language exposure.

6.2.1.2. Spatial Language and Spatial Memory

6.2.1.2.1 Spatial Language Use Predicts Spatial Memory Accuracy in a non-Robust way. Based on the literature showing a strong relation between spatial language use and spatial memory accuracy (e.g., Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Landau et al., 2010; Loewenstein & Gentner, 2005; Miller et al., 2016; Shusterman et al., 2011; Simms & Gentner, 2019) we expected to find a robust relationship between encoding spatial relations in language and remembering them later on. Results reported in **Chapter 4** provide additional evidence from speaking and native signing children for the views suggesting that encoding space through language predicts subsequent memory performance and extends this literature to encoding the spatial relations by children *themselves* (e.g., Dessalegn & Landau, 2008; Gentner, 2016; Lowenstein & Gentner, 2005). This, however, cannot be generalizable to all contexts as this finding was not replicated in **Chapter 5**. That is, encoding spatial relations with language did not predict better memory for spatial relations across native and late signers.

These contradictory results might suggest that the relationship between encoding with language and better memory representation may be weak thus cannot be observed robustly in all contexts. There could be several reasons for the lack of relationship between spatial encoding and spatial memory for native and late signers, on the one hand, and a significant relationship between speakers and native signers, on the other. First of all, late signers' data incorporate greater variation than that of the other groups. This variation, in turn, might have diminished the effect of encoding the spatial relation with language and subsequent memory accuracy in **Chapter 5**. Secondly, speakers, in general, might have generated stronger spatial representations when encoding spatial relation through using arbitrary spatial terms in **Chapter 4** that could have driven a stronger relationship between spatial encoding and spatial memory. Therefore, these two factors might have driven the contradictory results in **Chapters 4 and 5**.

To test this possibility, we conducted an exploratory analysis to test whether speakers and late signers differ in their memory performance. To do so, we analyzed whether or not having encoded the spatial relation between the objects predicted subsequent memory accuracy of speakers and late signers differently. We used a *glmer* model to test the fixed effects of Spatial Encoding (Spatial Encoding, No Spatial Encoding) and Language Group (Speaker, Late Signer) on binary values of Memory Accuracy (1 = Accurate, 0 = Not accurate) at the item level. Fixed effects of Spatial Encoding and Language Group were analyzed with centered contrasts (-0.5, 0.5). The model revealed a fixed effect of Spatial Encoding ($\beta = 0.98$, $SE = 0.29$, $p < 0.001$) and an interaction between Spatial Encoding and Language Group ($\beta = 1.23$, $SE = 0.57$, $p = 0.03$). To follow up on the interaction effect, we used *emmeans* package (Length, 2019): Separate comparisons for speakers and late signers showed that encoding with language predicted better memory accuracy for speakers ($\beta = -1.60$, $SE = 0.49$, $p = 0.001$) but not for late signers ($\beta = -0.37$, $SE = 0.30$, $p = 0.221$). Thus, as expected, failure to replicate the relationship between encoding the spatial relation with language and subsequent spatial memory in **Chapters 4 and 5** might have been driven by the differences between speakers and late signers. As mentioned above, encoding spatial relations through arbitrary and categorical forms in speech seems to drive a stronger relationship between encoding with language and subsequent memory for spatial relations and results in a significant relationship between spatial encoding and subsequent memory accuracy. Whereas, late sign language exposure seems to weaken this relationship possibly due to inter-individual variation among late signers. Yet, we acknowledge that there could also be many other variations across speakers and late signers that might have driven the contradictory results obtained from **Chapters 4 and 5**.

6.2.1.2.2. Type of Spatial Language Use does not Predict Spatial Memory Accuracy. One of the most robust findings is that encoding the spatial relation with different modalities (**Chapter 4**) or with different linguistic forms used in sign (**Chapter 5**) did not modulate the relation between spatial language and memory.

First of all, despite our initial expectation that encoding with iconic ways would lead to better memory due to the activation of the motor system and iconicity, descriptions that were encoded via "*speech alone versus sign*" or "*speech alone versus speech-plus-gesture*" did not modulate memory accuracy (**Chapter 4**). It is possible that encoding space through spatial terms that categorize the spatial relation in arbitrary and categorical ways might require effortful processing that can compete with encoding through visual-spatial forms (i.e., sign or speech-plus-gesture) despite iconicity and recruitment of the motor system leading to stronger representations. Hence, the effort of encoding spatial relations through arbitrary and categorical forms might have resulted in memory representations that are equally strong to encoding via iconic forms. This is especially plausible for descriptions of Left-Right relations as speaking children have difficulties in the cognitive understanding and linguistic encoding of Left-Right due to the symmetrical nature of this spatial domain (Abarbanell & Li, 2021; Benton, 1959; Harris, 1972; Piaget, 1972; Rigal, 1994, 1996; Sümer, 2015; Sümer et al., 2014).

To test this possibility, one could investigate Front-Behind relations that are easier to distinguish from each other or cognitively simpler relations such as In-On-Under that appear earliest in conceptual and linguistic development of space. One possibility is that encoding Front-Behind or In-On-Under in speech might not require the same effort as encoding Left-Right in speech and thus lead to weaker memory representations that cannot compete with iconic forms. Nevertheless, the fact that memory accuracy of the descriptions that are encoded through "*sign versus speech-plus-gesture*" also did not predict differences in memory accuracy implies that encoding with different modalities might generate subtle differences in spatial representations that might not reveal in our task. We discuss the possible task demands driving null results in the remainder of this section.

Secondly, contrary to what we have expected, encoding the spatial relation between the objects by also conveying information concerning the objects' shape did not generate stronger spatial representations than only encoding the spatial relation between the objects (**Chapter 5**). This is an interesting finding as previous research, using the very same stimuli and paradigm, has shown differences in deaf signers' visual attention prior to the description of spatial relations between objects by different linguistic forms (Manhardt et al., 2020). That is, encoding via classifier constructions that encode both the objects' shape information and the spatial relation between the objects recruited visual attention differently than that of linguistic strategies that only encoded the spatial relation between the objects. Together with Manhardt et al. (2020), the present findings suggest that the influence of spatial language on cognitive processes may emerge only during language use such as in visual attention while planning a linguistic description but such effects may not always last after the language use is completed (Landau et al., 2017). This interpretation may be in line with the previous accounts arguing that encoding space with language may result in temporary representations (Dessalegn & Landau, 2008; Landau et al., 2017) and depends heavily on task demands (see Ünal & Papafragou, 2016 for a discussion).

Finally, it is worth noting that when interpreting the null memory results of **Chapters 4 and 5**, it is important to consider the possibility that our experimental paradigm might have been susceptible to a multifaceted interaction between *picture superiority* (Paivio et al., 1968) and *production effects* (Conway & Gathercole, 1987).[15] Specifically, it is possible that having used pictures as the stimuli material coupled with having asked participants to overtly describe the target pictures during encoding might have boosted memory accuracy (see Zormpa et al., 2019 for the complex interplay between picture superiority and production effects in psycholinguistics research) and washed out possible effects of type of spatial encoding. Previous studies showing a facilitating effect of performing actions differ experimentally from our memory task (von Essen & Nilsson, 2003; Zimmer & Engelkamp, 2003). For instance, the verbal encoding condition of these studies was operationalized as reading list of words silently (Zimmer & Engelkamp, 2003) or hearing a list of

[15] Picture superiority effect refers to the phenomenon that pictures/images are more likely to be remembered than words. Production effect refers to the phenomenon that words read aloud are more likely to be remembered than words read silently.

words that was read to participants (von Essen & Nilsson, 2003). Together, in the present thesis, the fact that participants were actively describing stimuli items and these items were pictures might have diminished the differences between encoding with different modalities (**Chapter 4**) or with different linguistic forms in sign (**Chapter 5**).

In addition, it is also possible that not instructing participants to respond as quickly as possible in the memory task might have diminished the differences in memory accuracy across encoding with different modalities (**Chapter 4**) or with different linguistic forms in sign (**Chapter 5**). Possibly, participants took their time to find the correct answer.

Therefore, the current paradigm might have had limited potential to detect differences in spatial memory. We suggest further research to consider the above-mentioned task demands in designing experiments to further our understanding of encoding with language and its relations to subsequent memory.

6.2.2. Methodological Contributions of the Current Thesis in Investigating the Spatial Language Use and Its Relations to Spatial Memory

In addition to the above-mentioned theoretical contributions, the current thesis offers several methodological contributions in investigating the development of spatial language use and the relationship between spatial language use and spatial memory.

The first methodological contribution of this thesis is related to the investigation of spatial language development in late sign language exposure. First of all, the data collected in this thesis have no parallels in the literature in terms of the number of participants from this population. Recruiting a larger sample of participants is important especially for populations that are prone to have inter-individual variation (e.g., late signers). Secondly, to our knowledge, the current thesis is first to compare late signing children to their native signing peers who were matched in terms of many respects (i.e., age, schooling experience, non-verbal cognitive skills). Controlling several factors that could account for differences between late and native signers is important because it helps isolate *late sign language exposure* as the factor that differs between the groups – at least to a considerable extent.

Another methodological contribution of this thesis is the way the investigation of the relationship between spatial language use and spatial memory accuracy is operationalized. Previous studies investigating this relationship reported a strong relation between knowledge and use of spatial terms and spatial memory performance (Abarbanell & Li, 2021; Dessalegn & Landau, 2008; Gentner et al., 2013; Hermer-Vasquez et al., 2001; Lowenstein & Gentner, 2005; Miller et al., 2016; Shusterman et al., 2011; Simms & Gentner, 2019). Some of these studies provided correlational evidence between spatial language use and spatial memory performance (e.g., Hermer-Vasquez et al., 2001; Shusterman et al., 2011; Simms & Gentner, 2019). Others provided experimental evidence through tasks in which spatial terms were experimentally introduced by the experimenters (Dessalegn & Landau, 2008, 2013; Lowenstein & Gentner, 2005). The current thesis did not assume that there will be a variation in language use due to modality or timing of language exposure or it did not introduce the spatial terms experimentally. Rather, it empirically established this by asking participants to remember the *same* picture that they had described previously (e.g., also see ter Bekke et al., 2019, under review for a similar design used for encoding motion evens in speech and gesture and subsequent memory).

6.2.3. Limitations and Future Directions

Studies reported in this thesis also contained limitations and generated ideas for future research. Here, we discuss a few of these.

6.2.3.1. Developing Linguistic Conventions beyond Manual Articulators

In the current study, we focused on manual articulators in sign and co-speech gestures to maintain similarity to previous research on the development of encoding spatial relations. However, in addition to the manual articulators, head/torso movements and eye-gaze direction may provide important contributions to our understanding of the role of multimodal communication for the development of spatial language use in sign and co-speech gestures. This calls for further research to establish systematical and conventional ways of integrating those aspects in investigating the development of multimodal communication and their relations to cognition.

6.2.3.2. Considering Different Aspects of Language Use

First of all, particularly for TİD, the current thesis collapsed different types of classifier constructions into one category (i.e., Entity and Handling; see Zwitserlood, 2012). However, the acquisition of different types of classifier constructions along with the handshape differences at the phonological level (see Janke & Marshall, 2017 for a detailed coding scheme) might further reveal differences between late and native signers. Such an investigation has the potential to reveal some inferences about how late signers go about learning to use classifier handshapes.

Secondly, focusing on the development of different types of classifiers might provide further insights into the relation between spatial language use and spatial memory. For instance, classifier handshapes that are categorized as handling classifiers indicate the ways in which individuals act on the objects that they represent compared to entity classifiers that are representing objects' shape information. It is possible that encoding spatial relation through handling classifiers might create better memory representations than entity classifiers generating deeper involvement of the motor system due to the activation of action representations (Cohen, 1989; Nilsson, 2000).

Thirdly, the current thesis focused on the presence of spatial encoding between the Figure and Ground items as a factor in understanding the development of spatial language use. An alternative way to capture developmental patterns in learning to express locative relations could be to focus on mention of Figure-Ground order across signers and speakers on the one hand (see Manhardt, 2020 for Sign Language of the Netherlands; Perniss, 2007 for German Sign Language; Sümer, 2015 & Sümer et al. 2013 for TİD) and across late and native signers on the other. Investigating word order conventions may further enhance our understanding of the complex interplay between different aspects of linguistic mastery, conceptual complexity, age, and timing of language exposure. This is an open area for research in the context of late sign language acquisition and results might uncover whether mention of Figure-Ground order in encoding spatial relation between the two objects is an aspect of linguistic development that is prone to be affected by late exposure.

Finally, it would be good to check the validity of these findings in children's every day and contextual uses embedded in a larger discourse. It is also important to note that the current thesis focused on production but it is also important, as a next step, to understand spatial language comprehension in different modalities and as a function of late exposure by signers and speakers to get a more global understanding of spatial language development.

6.2.3.3. Considering Simpler Designs to Elicit Spatial Descriptions of Children

In the current thesis, participants were asked to provide their picture descriptions in the absence of the stimuli (i.e., during visual white noise). This manipulation was initially done to prevent children pointing at the screen to indicate the objects rather than introducing them in speech/sign. However, this manipulation might have made the task harder for children as they have to both remember the picture and generate a linguistic description of it. Moreover, it might have also resulted in increased gesture use as gestures might have helped children maintain the spatial image as they had to remember from their short-term memory for description (see Wesp et al., 2001). These possibilities call for further research to develop designs that give no room for the requirement for short-term memory stores.

6.2.3.4. Considering Individual Variation within Groups

The current thesis aimed at matching groups in certain respects such as age, schooling experience, visual-spatial working memory. However, internal sources of variation within groups may also help understand the relationship between spatial language use and spatial memory. Moreover, these variations could also be more salient for specific groups such as late signers, who have the most atypical language immersion histories, than others. Therefore, further studies should aim at focusing on individual differences by possibly increasing the number of cognitive and linguistic measures and the number of participants tested in each group. Please note that studies focusing on individual variation often require more participants than we could have tested in this study, as studying with special populations restricts the number of participants.

6.2.3.5. Investigating the effects of Late Language Exposure Longitudinally

The current thesis compared late signing children with 2 years of sign language exposure to their age-matched native signing peers to investigate the development of spatial language use and its relations to spatial memory accuracy. Nevertheless, in order to provide a complete picture of linguistic and cognitive development of space in late sign language exposure cases, further research should concentrate on testing the same children before and after language exposure and comparing them to native signing children at each time point. This approach will allow to definitely uncover the effects of late exposure on the linguistic production of space and its relations to spatial memory accuracy.

In addition, the current study focused only on 2 years after exposure to sign language, nothing is known at which time point late signing children start to show adult-like linguistic patterns in encoding Left-Right relations. To follow up on this, a possible systematic way to investigate the effects of late sign language exposure may be to collect data from groups of late signing children who are 10-years-old (4 years after exposure to sign) and adolescents who are 12-years-old (6 years after exposure to sign), or even later. This approach will help discover the linguistic development of space more systematically.

6.2.4. Societal Implications

Current findings have implications for developing intervention programs for deaf children with hearing parents prior to language exposure and implications for educational contexts of signing and speaking children.

Deaf children's access to a sign language must be considered as a fundamental right. Nevertheless, in many cases, this right is not granted to them. Findings obtained from the current thesis have the potentials to provide informed decisions for policymakers in some respects.

First of all, findings have implications for developing intervention programs for deaf children with hearing parents. For instance, results of **Chapter 3** underlined how important it is for deaf children with no access to sign language to have platforms that allow them to gather with other deaf signers, especially native signers who have been exposed to language from birth. Even having only two years of exposure to sign language (in the school environment from their deaf peers in the Turkish context) seems to scaffold their sign language development even despite any formal instructions in sign by the teachers. On the one hand, this evidence might be useful for the policymakers of underdeveloped countries. In underdeveloped countries, deaf schools may not be established due to reasons such as underdeveloped curricula for the deaf or the absence of sign language teacher programs. However, establishing deaf schools that provide oral educations could also be useful as these schools allow for horizontal language transmission opportunities for children. On the other hand, this evidence can also be useful for the policiymakers of developed countries where deaf children are offered early interventions that focus on speech therapy and hearing aids. Although some deaf children might benefit from these strategies greatly, for some, these strategies may not result in optimal outcomes for language development (see Hall et al., 2019 for a detailed review). An alternative approach may be to develop intervention programs that offer sign language exposure. These programs could simply be creating opportunities for deaf children to meet with other deaf children. Providing earlier language immersion instances before the official start of the school for the deaf might have a great potential for supporting the language development of deaf children with hearing parents.

Secondly, findings obtained from the current thesis have implications for building educational strategies for signing and speaking children. First of all, especially for late signing children, including teaching a sign language as part of an official curriculum has the potential to enhance their language development because these children have only limited access to sign language compared to their native signing peers. Moreover, the findings obtained from the current thesis could also be used as a guide for preparing curricula for teaching sign language to deaf children in general and late signing children in particular. As shown in **Chapters 3 and 5**, children start with the simpler forms of language (e.g., pointing) rather than exclusively using morphologically complex classifier constructions from an early age onwards. It is possible to facilitate linguistic development of late signers by providing them classroom activities that incorporate narrations using classifier constructions. These activities might help children get exposed to classifier constructions by teachers or classmates and help them experiment with using these forms by themselves. In addition, for speaking children, the present thesis also has implications for considering gestures as part of assessment tools in education. Present findings add to the existing literature that gestures may reveal young children’s understanding of a concept that is not readily accessible to speech (Alibali, 1999; Church & Goldin-Meadow, 1986; Perry et al., 1988; Perry & Elder, 1997) and how gestures may function as the connection between explicit and implicit knowledge

(McNeil, 1992). Together with this literature, present results call for developing assessment methods that do not solely depend on recall or recognition of the learning material in speech only but also leave room for multimodal ways to express this material in the classroom setting.

6.3. Conclusion

The current thesis contributed to a larger body of knowledge suggesting that the development of spatial language use is shaped by an intricate interplay between the cognitive and linguistic factors. In doing so, it focused on the variation in language modality and variation in the timing of sign language exposure as new perspectives into this interplay. Results have shown that although the variation in language modality and timing of sign language exposure influence development of spatial language use, these variations do not necessarily predict the relationship between spatial language use and spatial memory. Possible theoretical and methodological implications have been addressed to guide future research.

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Abbreviations and Transcript Conventions

Abbreviations

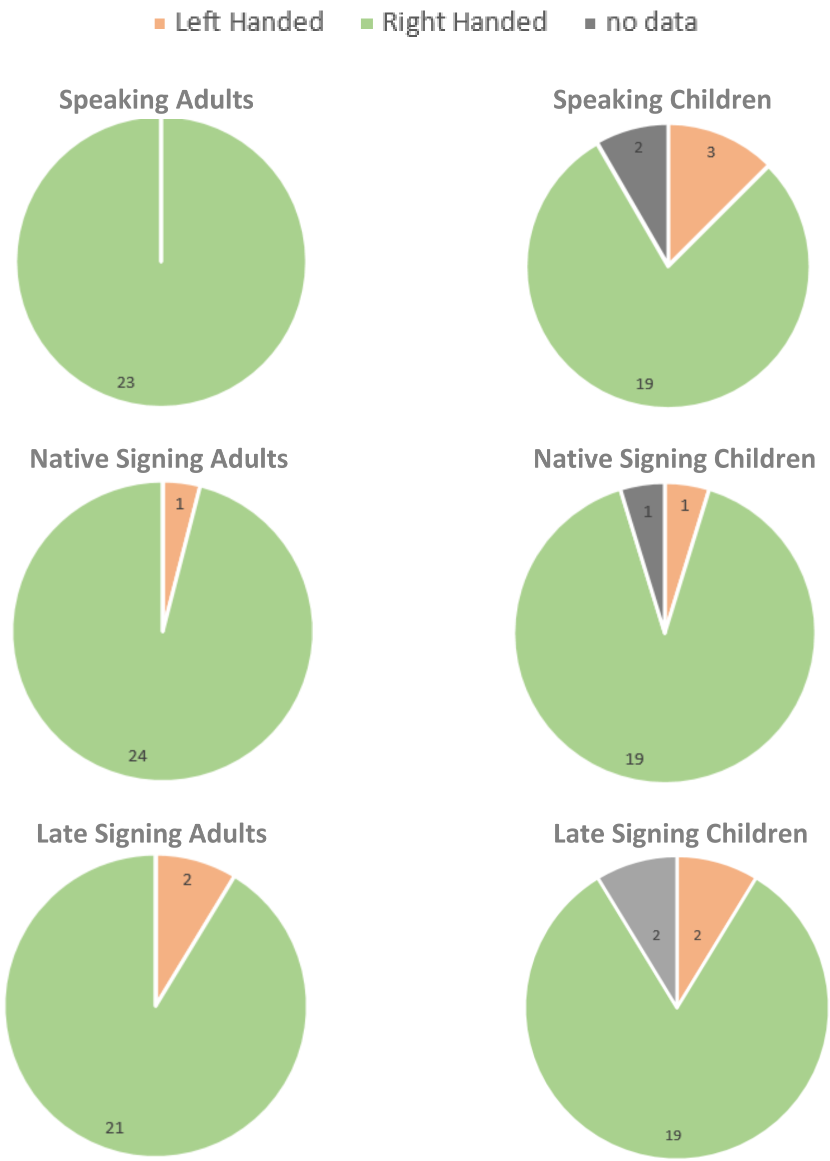
DIM	Diminutive
GEN	Genitive
LOC	Locative
L2	A person's second language
POSS	Possessive
PREP	Preposition
RQ	Research Question
TİD	Turkish Sign Language (Türk İşaret Dili)

Transcript Conventions

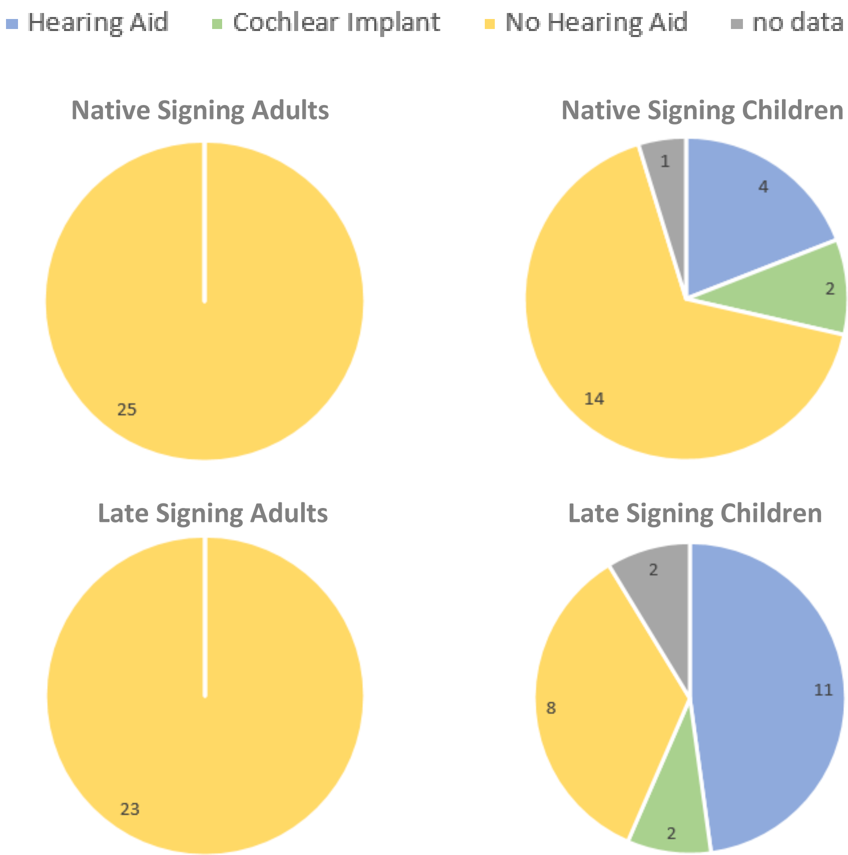
CUP	Lexical sign
CL(long)	Classifier followed by the classificatory feature or identity of the referent
CL(long)$_{Loc}$	The location of the referent presented with a classifier is in the subscript
LH	Left hand
LV	Lexical Verb Placement
RH	Right hand
Pointing(Pencil)$_{Loc}$	The location of the referent presented with pointing is in the subscript
Tracing(Pencil)$_{Loc}$	The location of the referent presented with tracing is in the subscript
----HOLD----	Sign form holds

Appendices

Handedness of the participants presented in **Chapter 2, Chapter 4, and Chapter 5**. The numbers in the graphs represent the number of participants in each category. Numbers add up to the total number of participants in a given participant group.



Use of hearing devices across the deaf participants reported in **Chapter 2, Chapter 4, and Chapter 5.** The numbers in the graphs represent the number of participants in each category. Numbers add up to the total number of participants in a given participant group.



Notes. As teacher reports and checks by the experimenter showed, the deaf children were unable to respond when they were called by their names in the auditory modality despite some of them were using hearing aids. This suggests that hearing aids did not provide optimal hearing outcomes.

Nederlandse Samenvatting

Al vanaf zeer jonge leeftijd observeren en interacteren kinderen met de objecten om hen heen. Objecten kunnen op verschillende manieren gepositioneerd zijn ten opzichte van elkaar; zo kan een object bijvoorbeeld *op* of *achter* een ander object staan, of *links* of *rechts* ervan. Het nadenken over en beschrijven van zulke ruimtelijke relaties zijn fundamentele vaardigheden die kinderen zich eigen moeten maken. Dit proefschrift onderzoekt de vraag hoe kinderen die vaardigheden ontwikkelen, en welke factoren daarbij een rol spelen.

Tot nu toe is verondersteld dat er een wisselwerking is tussen cognitieve en talige factoren als het gaat om de ontwikkeling van ruimtelijke taal. In eerdere studies is die interactie onderzocht door te focussen op verschillen tussen gesproken talen, waarbij enkel is gekeken naar de taalontwikkeling van horende kinderen die sinds hun geboorte zijn blootgesteld aan een gesproken taal. Dit proefschrift gaat een stap verder door niet alleen te kijken naar de ontwikkeling van ruimtelijke taal in spraak, maar door ook te onderzoeken hoe die ontwikkeling zich manifesteert in handgebaren en gebarentaal. Tevens is de leeftijd waarop dove kinderen voor het eerst blootgesteld werden aan gebarentaal meegenomen in het onderzoek. Door deze twee factoren (taalmodaliteit en leeftijd van blootstelling) te onderzoeken biedt dit proefschrift nieuwe inzichten in de relatie tussen talige en cognitieve factoren die een rol spelen bij de ontwikkeling van ruimtelijke taal. Er is tevens onderzocht hoe variatie in ruimtelijke beschrijvingen kan voorspellen hoe goed kinderen die ruimtelijke relaties vervolgens onthouden. Om deze vragen te beantwoorden is onderzoek gedaan onder twee groepen in Istanbul: horende kinderen en volwassenen die Turks spreken, en dove kinderen en volwassenen die Turkse Gebarentaal (*Türk İşaret Dili* [TİD]) gebruiken.

De bevindingen van dit proefschrift dragen bij aan onze kennis over hoe de ontwikkeling van ruimtelijke taal tot stand komt door een complexe wisselwerking van cognitieve en talige factoren. De resultaten laten zien dat de twee onderzochte factoren (taalmodaliteit en leeftijd van blootstelling aan gebarentaal) invloed hebben op de ontwikkeling van ruimtelijke taal, maar dat deze factoren weinig voorspellende waarde hebben als het gaat om de relatie tussen het beschrijven versus onthouden van ruimtelijke relaties. Tenslotte komen ook de theoretische en methodologische implicaties voor vervolgonderzoek aan bod.

About the Author

Dilay Zeynep Karadöller Astarlıoğlu was born on January 2, 1989, in İstanbul, Turkey. She obtained a bachelor's degree in Psychology (2013) and a master's degree with honors in Psychological Sciences (2016) at Boğaziçi University, Turkey. Dilay then joined Multimodal Language and Cognition Group directed by Prof. dr. Aslı Özyürek at Max Planck Institute for Psycholinguistics and Radboud University, Nijmegen as a PhD student. During her PhD, she conducted research reported in this thesis, took part in organization committees of several workshops and conferences, and acted as a PhD representative for International Max Planck Research School for Language Sciences between 2016 and 2017. In addition, she worked as a part-time lecturer at several institutions, such as the Department of Language and Communication at Radboud University, the Department of Psychology at Boğaziçi University, and the Department of Psychology at Koç University. Currently, she continues her academic endeavor as a postdoctoral researcher in the Language and Communication lab directed by dr. Tilbe Göksun at Koç University and as a part-time faculty member in the Department of Psychology at Middle East Technical University.

Author Publications

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