DEVELOPMENT OF MULTIMODAL EXPRESSIONS OF SPACE IN SPEECH AND GESTURE: THE CASE OF SAGITTAL AND TOPOLOGICAL SPATIAL RELATIONS

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ABSTRACT

Previous literature has shown that learning to communicate about space follows a lengthy timetable. However, prior work has shown that children can express some concepts, including spatial relations, in gestures prior to expressing them in speech. Do children use gestures with under-informative descriptions for spatial relations that are acquired earlier in development such as topological and viewpoint dependent sagittal spatial relations? Furthermore, within those spatial relations that are acquired earlier, are there differences in the use of under-informative speech plus gesture combinations? Finally, when speech and gesture are both considered, do developmental differences between adults and children diminish or disappear completely? The present study addresses these questions by looking at children's spatial expressions in speech only, gestures, and speech plus gesture. We contrasted descriptions of two spatial descriptions that vary in their complexity. Participants (24 children and 23 adults) were monolingual Turkish speakers who described a target picture (indicated by an arrow) to an addressee. Target pictures depicted either topological relations (in-on) or viewpoint-dependent relations in the sagittal axis (front-behind). Our results showed that children and adults produced informative spatial expressions equally frequently for topological spatial relations in their speech. However, children produced informative spatial expressions less frequently than adults for viewpoint dependent sagittal spatial relations in their speech. Children produced spatial expressions that informative when gesture were considered more for viewpoint dependent sagittal spatial relations. Children produced spatial expressions that informative when gesture were considered less for topological spatial relations because they were already informative in their speech. Lastly, children's frequency of informative spatial expressions reached the adults' level in speech plus gestures. Gestures revealed earlier expression of viewpoint dependent sagittal spatial relations. However, the total speech plus gesture frequency of informative spatial expression did not add new information for topological spatial relations. This study demonstrated the interactions between multimodal expressions of spatial relations and their complexity as seen in their order of acquisition.

ÖZET

Önceki çalışmalar uzamsal alanda iletişim kurmanın uzun bir gelişimsel çizelgeyi takip ettiğini göstermektedir. Ancak, yine önceki çalışmalar çocukların uzamsal ilişkiler de dahil olmak üzere bazı kavramları jest kullanarak konuşmalarından daha erken ifade edebildiklerini de göstermektedir. Çocukların nesneler arasındaki ilişkiyi yeterince açıklamayan kelimeler ile birlikte jest kullanıp kullanmadıkları, topolojik ve sagital eksendeki uzamsal ilişkiler gibi gelişimsel olarak daha erken yaşlarda öğrenilen uzamsal ilişkilerde test edilmemiştir. Ayrıca, daha erken öğrenilen uzamsal ilişkiler arasında yeterince açıklayıcı olmayan kelimeler ile jest kullanımında bir fark olup olmadığı incelenmemiştir. Son olarak, konuşma ve jest beraber değerlendirildiğinde, çocuklar ve yetişkinler arasındaki gelişimsel farkların azalıp azalmadığı veya tamamen kaybolup kaybolmadığı bilinmemektedir. Bu çalışmada, çocukların ve yetişkinlerin konuşmalarına, jestlerine, konuşma ve jestlerine birlikte bakılarak bu sorulara cevap aranmıştır. Bunun için çocuk ve yetişkinlerin zorluk derecelerinde farklılık gösteren iki uzamsal ilişkiyi konuşma ve jestlerinde nasıl ifade ettikleri kıyaslanmıştır. Anadili olarak Türkçe konuşan katılımcılardan (24 çocuk ve 23 yetişkin) farklı uzamsal ilişkileri gösteren 4 fotoğraf arasından ok ile gösterilen hedef fotoğrafı tanımlamaları istenmiştir. Bu görseller arasında ok ile gösterilen hedef uzamsal ilişkiler topolojik (içinde-üstünde) ya da sagital eksendeki bakış açısına göre değişen uzamsal ilişkilerden oluşmaktadır. Sonuçlar çocuk ve yetişkinlerin konuşmalarında topolojik uzamsal ilişkileri eşit sıklıkla bilgilendirici ifade ettiklerini göstermektedir. Ancak, çocukların konuşmalarında sagital eksendeki bakış açısına göre değişen uzamsal ilişkileri

yetişkinlere göre daha az sıklıkla bilgilendirici ifade edebileceği bulunmuştur. Çocukların nesneler arasındaki ilişkiyi yeterince açıklamayan ifadeler ile birlikte jest kullanımının, sagital eksendeki bakış açısına göre değişen uzamsal ilişkileri tanımlamada topolojik ilişkileri tanımlamaya göre daha sıklıkla kullandıkları bulunmuştur. Çocukların nesneler arasındaki ilişkiyi yeterince açıklamayan ifadeler ile birlikte jestleri topolojik ilişkiler için daha az kullandıkları bulunmuştur. Buna sebep olarak çocukların topolojik uzamsal ilişkilerin konuşma ile ifadesinde zaten yeterince bilgilendirici oldukları gösterilebilir. Son olarak, konuşma jestler ile birlikte değerlendirildiği zaman, çocuklar ile yetişkinler arasındaki gelişimsel farkların kapandığı gözlemlenmiştir. Çocuklar jestleri aracılığı ile sagital eksendeki bakış açısına göre değişen uzamsal ilişkilerde erken gelişim göstermişlerdir. Ancak, konuşma ve jestlerin toplam bilgilendirici sıklığı topolojik uzamsal ilişkilerin ifade edişine yeni bir bilgi eklememiştir. Bu çalışma farklı uzamsal ilişkilerin ve bu ilişkilerin edinim sırasına göre zorluk derecelerinin konuşma ve jestlerde ifade edilişinde bir etkileşim bulmuştur.

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CHAPTER 1

INTRODUCTION

Spatial understanding and spatial language are fundamental cognitive abilities. Spatial language has been found to be related to children's mathematical development (Bower et al., 2020), attention (Miller & Simmering, 2018), and memory about space (Feist & Gentner, 2007). We use spatial terms (e.g., in, on, front, behind, left, and right) in math, during route descriptions, and while searching for a missing object. Even though spatial language is one of the early developing skills, it still follows a long developmental trajectory (Clark, H. 1973; Johnston, 1985; Johnston & Slobin, 1979). In many cases, children cannot informatively describe spatial relations (Johnston, 1984; Sümer et al., 2014). However, children frequently use gestures when their spatial descriptions in speech are under-informative (Furman et al., 2014; Göksun et al., 2010; Karadöller et al., 2021, under review). For instance, a child can describe an object's location "the toy is there" in speech and use a gesture such as pointing to indicate a specific location. This way, gesture and speech together could make a spatial description more informative. Nevertheless, there are limited studies investigating when and how children use these kinds of speech gesture combinations. Furthermore, when speech is considered together with gestures, the developmental differences between children and adults in producing informative spatial descriptions might decrease or disappear. The present study addresses these issues by investigating children's spatial expressions first in speech and then in speech plus gesture. To understand when and how children use these kinds of multimodal expressions, we contrast descriptions of two spatial relations that vary in their complexity.

CHAPTER 2

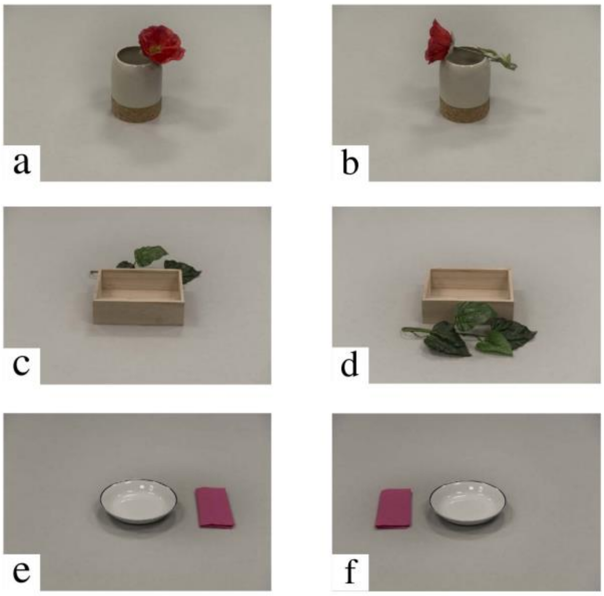
LITERATURE REVİEW

2. 1. Locative Spatial Relations

Locative spatial relations entail the relations between at least two objects. These two objects are known as the figure and the ground objects. The figure objects are smaller, foregrounded, and more mobile than the ground objects (Talmy, 1985). The ground objects are bigger, backgrounded, and less mobile than the figure objects (Talmy, 1985). Figure and ground objects may engage in various spatial relations, such as support, containment, occlusion, or visibility. Figure-ground spatial relations might remain the same regardless of or change depending on the observer's point of view. For example, topological spatial relations, such as containment (Figure 1a) and support (Figure 1b) remain the same from different perspectives (Levinson & Wilkins, 2006). By contrast, some locative spatial relations depend on the observer's viewpoint. Spatial relations on the sagittal and lateral axis, the change according to the observer's perspective. For instance, in the sagittal axis, a person observing the occlusion relation in figure 1c would have observed a visibility relation if they were observing from the opposite side. Similarly, a person observing the visibility relation in figure 1d, would have observed an occlusion relation if they were observing from the opposite side. Likewise, in the lateral axis, a person observing the figure object on the right side in figure 1e, would have observed it on the left side if they were observing from the opposite side. Similarly, a person observing the figure object on the left side in figure 1f would have observed it on the right side if they were observing from the opposite side.

Figure 1

Locative Spatial Relations: Viewpoint independent (in-on) (a&b), Sagittal viewpoint dependent (front-behind) (c&d), and Lateral viewpoint dependent (left-right) (e&f).



2. 2. Encoding Locative Spatial Relations in Language

The linguistic structures that encode spatial relations vary considerably across languages. Spatial relations between two objects might be encoded with adpositions (i.e., preposition and postposition), spatial nouns, or case markers. For example, in English, topological containment spatial relations are expressed with the spatial noun “in”, and support is expressed with the spatial noun “on”. However, in Dutch, attachment spatial relations are expressed with the spatial preposition “ann”, and support is expressed with “op” spatial proposition. On the other hand, Spanish expresses support, containment and attachment spatial relations with spatial preposition “en”. Some languages encode spatial relations in a morphologically more complex way. For instance, In Turkish, which is the target language of the present study, spatial relations are expressed with spatial nouns and postpositions. Locative case markers (LOC) (-de/-da) are attracted to the spatial noun or the noun phrase expressing the object. Also, the possessive case marker (POSS) (e.g., -nın/ın) attached to the spatial noun and ground object takes a genitive marker (GEN) (e.g., -ın). Example 1 gives in detail how the support spatial relation is expressed in Turkish.

(1)	Masa-nın	üst-ün-de	kutu	var.
	table-GEN	on-POSS-LOC	box	there.is
	GROUND	SPATIAL RELATION	FIGURE	

“There is a box on the table.”

Sagittal viewpoint dependent spatial relation, occlusion, is encoded with the spatial noun “behind” and visibility is encoded with the spatial noun “front” in English. Similarly, in Dutch occlusion is encoded with the spatial noun “achter” and visibility is encoded with the spatial noun “voorkant”. In Turkish occlusion and visibility are encoded in a morphologically more complex way. Occlusion and visibility spatial relations are expressed with spatial nouns and postpositions. Occlusion is expressed with “arkasında” (*lit.* “at its behind”), visibility is expressed with “önünde” (*lit.* “at its front”) in Turkish. Example 2 gives detail how the occlusion relation is expressed in Turkish. Lateral viewpoint spatial relations are encoded in in similar ways, with spatial nouns “left” and “right” in English, and “sağında” and “solunda” in Turkish.

(2)	Masa-nın	arka-sın-da	kutu	var.

table-GEN	on-POSS-LOC	box	there.is
GROUND	SPATIAL RELATION	FIGURE	

"There is a box behind the table."

2. 3. Acquisition of Spatial Language

According to many scholars, learning to encode spatial relations – at least to some extent – entails mapping cognitive understanding of spatial relations onto spatial terms in the language (Clark E., 2004; Johnston, 1985, 1988). For spatial language acquisition, children first need to have a conceptual understanding of space. Then, they map spatial terms in language onto those already existing concepts (for an alternative hypothesis see Bowerman, 1996a, 1996b; Bowerman & Choi, 2001). Studies done with children from different spoken languages suggest that children learn spatial relations in a predictable order (Clark E., 2004; Johnston & Slobin 1979). Importantly, this predictable order parallels the development of non-linguistic cognitive understanding of spatial relations suggesting that nonverbal cognitive development of locative spatial relations may determine the linguistic development of space.

Consistent with this view, a large body of research shows that children develop non-linguistic understanding of spatial relations before learning how to express them in their language (Clark E., 2004). For instance, Casasola et al. (2003) found that six-month-old infants can understand containment locative spatial relations in a looking-time based categorization task, but they learn support spatial relations later. Also, 9–14-month-old infants can understand the contrast relations of tight-fit containment and loose support (Casasola & Cohen, 2002; McDonough et al., 2003). These pieces of evidence suggest that children have a certain spatial understanding before spatial language development.

When children learn to take others' perspectives, they also develop an understanding of viewpoint dependent spatial relations (Johnston, 1984; Kuczaj & Maratsos, 1975; Levine & Carey, 1982). Sagittal viewpoint dependent spatial relations develop around age 4 when children understand the occlusion and visibility spatial relations (Johnston, 1984). Around age 2, children take their bodies as a reference point and understand their own front and behind sides (Kuczaj & Maratsos, 1975; Levine & Carey, 1982). Later, they recognize the front and behind sides of objects that intrinsically have a front and a behind side (e.g., a house). Around age 4, they begin to take a front and behind perspective without reference to their bodies, and they become able to take another person's or objects perspective (E. Clark, 1980; Johnston, 1984; Kuczaj & Maratsos, 1975; Levine & Carey, 1982). The non-linguistic development of spatial relations in the lateral axis also follows a similar pattern (Elkind, 1961; Harris, 1979; Shusterman & Li, 2016). However, since the lateral relations are symmetrical (i.e., the left side of an object is the same as the right side) they develop later.

Another body of evidence supporting the mapping hypothesis for spatial language acquisition comes from cross-linguistic developmental studies. As already mentioned, the acquisition of spatial language follows a predictable order across languages regardless of morphological complexity, and lexical diversity (Johnston & Slobin, 1979). Furthermore, the order of linguistic acquisition of spatial terms parallels the non-linguistic development of spatial relations (Johnston, & Slobin, 1979; Kuczaj & Maratsos, 1975).

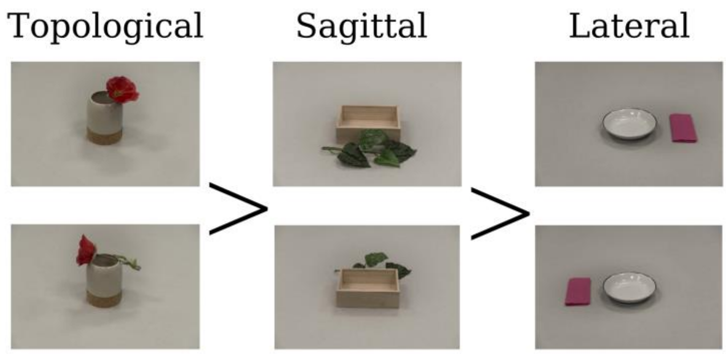
Specifically, viewpoint independent topological spatial relations are the earliest spatial relations, and children learn how to linguistically express containment and support first at around age 2 (Bowerman & Choi, 2001; E. Clark, 1973; Johnston, 1985, 1988; Johnston & Slobin, 1979). Johnston and Slobin (1979) found that children between 2- and 4-year-olds successfully expressed in and on spatial relations in a spatial language task. That linguistic evidence comes from the English language, but the spatial language production age follows similar patterns in different languages (Johnston & Slobin, 1979; de Leo. L, 2001).

After topological spatial relations, children learn to express viewpoint dependent sagittal relations such as visibility and occlusion. Children successfully produce front and behind spatial terms at age 4 (Johnston, 1984). Children learn to express intrinsic front and behind feature objects like cars, or teddy bears before non-intrinsic like paper, or box (Kuczaj & Maratsos, 1975; Levine & Carey, 1982). Intrinsic featured objects are easier than non-intrinsic, because faces and direction of motion gives more cues for front and behind. Furthermore, when children learn to express non-intrinsic feature objects relations, they might use general spatial terms to express viewpoint dependent sagittal spatial relations like next to, and side (Johnston, 1984; Sümer et al., 2014). Thus, in sagittal axis, front and behind relations might also elicit the side and next to which can be considered under-informative spatial expressions.

The occlusion and visibility feature gives sagittal viewpoint dependent spatial relations additional cues, so these relations are asymmetrical. Levine and Carey (1982) found that children linguistically produced behind spatial terms earlier than front. Furthermore, Grigoroglou et al. (2019) conducted a study to investigate the developmental patterns in the use of front and behind with motion events. They compared 3-year-olds, 4-year-olds, and adults for their visibility and occlusion relation expressions with Greek and English speakers. Children in both age groups produced the spatial term behind more than front, but there was no such difference in spatial term production of adults. These findings suggest that children began to express front and behind unsymmetrically. They were produced the spatial term behind earlier, possibly because there are additional features to make behind more distinctive than front. Moreover, in the same experiment, Grigoroglou et al. (2019) established two different occlusion conditions: bigger ground objects that fully occluded the figure objects and smaller ground objects that occluded the figure objects to a lesser extent. Children produced more behind spatial terms when the ground object was bigger and entirely occluded the figure object. However, adults produced behind spatial terms equally for bigger and smaller ground objects. In a follow up experiment, they extended the motion paths and tested whether or not it would change the path description. In this case, their result showed that adults expressed occlusion more than visibility like children. These results suggest that occlusion may be mentioned more than visibility due to the fact that a change in visibility present in “behind” (but not in “front”) relations may be more noteworthy to be mentioned. Thus, both children and adults pragmatically express the occlusion relation more than visibility.

Lastly, children produce viewpoint dependent lateral axis spatial relations left-right at the latest in the developmental trajectory (Clark, H. 1973; Elkind, 1961). Unlike the viewpoint dependent sagittal spatial relations, viewpoint dependent lateral relations have no additional clues and are symmetrical. In early language acquisition, children use self-reference and describe the object locations from their perspective. To discriminate left-right spatial expression, children need first to identify their left and right body parts (Benton, 1959). Elkind (1961) measured the left and right spatial language production of children aged 5 to 11 in different tests. The results demonstrated that children began to be successful at left and right language production tests at ages 7 and 8. Seven- and eight-year-old children were successful at left and right tests for their own body and moderately successful for the other objects. However, 11-year-old children successfully produced left and right for the other objects. Eight years old children used more under-informative spatial terms (e.g., next to, side) for lateral viewpoint dependent spatial relations than sagittal viewpoint dependent spatial relations (Sümer et al., 2014). This result shows that children can express left-right spatial relations at ages 7 and 8, but it is still more challenging than front-behind spatial expression.

Figure 2
Developmental order of spatial language acquisition



The above mentioned developmental patterns in the acquisition of spatial language may be attributed to the complexity of spatial relations. Clark, H. (1973) suggests that human spatial understanding has three levels: ground, vertical front-behind, and vertical left-right. The complexity hypothesis advances from these three levels, and it asserts that spatial relations development and spatial language acquisition starts with the simple level and go into the complex ones. Children learn to communicate about easier spatial relations earlier in development. Topological spatial relations develop first because they do not require perspective taking. Viewpoint dependent sagittal develops before then lateral because occlusion and visibility give additional clues for distinguishing sagittal relations from each other. The viewpoint dependent lateral axis develops last, and it is the most difficult one because of its symmetrical features. The cognitive difficulty order has a significant role in the developmental pattern of spatial language (Johnston, 1984).

2. 4. The Roles of Co-speech Gestures

Prior evidence presented above suggests that spatial language acquisition follows a long developmental trajectory. However, this evidence comes from studies focusing on children's spatial expressions in speech only. Nevertheless, speakers frequently use gestures together with speech while in their communication and gestures convey new information into the to their conversation partner (McNeill, 2005). Importantly, in many aspects of cognitive and linguistic development, gestures reveal earlier development (Furman et al., 2014; Hostetter, 2011; Özçalışkan & Goldin-Meadow, 2009, 2011; for an overview see Avcılar et al., 2021). Gestures serve a communicative function by clarifying ambiguous speech or providing information missing from speech (Goldin-Meadow, 1999). Specifically, supplementary gestures provide information that is not present in speech. For instance, speakers may utter "side" in speech and point towards the left side. The pointing gestures give additional information about the specific location and thus clarify which side the speaker is referring to.

Gestures also serve a self-orientated function by regulating mental states. The fact that children may express information missing from speech more easily and thus earlier in gesture can be explained by the *Gesture for Conceptualization Hypothesis* (Kita et al., 2017). According to this hypothesis, gestures visually represent action, motion, shape, and location and those representations shape how we conceptualize information for thinking and speaking. Gestures conceptualize spatial-motoric information by activating, manipulating, packaging, and exploring them in visually motivated ways. Thus, these four ways shape the schematization process of information. Moreover, Kita et al. (2017) claim that we produce gestures because while gesturing about the action, we seem to also practically perform the actual action. For instance, placing an object into the gesture space practically places an object in its actual location. We can visually express an action, motion, shape, and location with gestures. Gestures represent the real action visually (i.e., schematize) to convey additional information into the speech. This activates the spatial motoric information. Finally, communicative and self-orientated functions of gestures are not mutually exclusive. The schematization of the visual-spatial information in gesture may also facilitate communication. Thus, the two functions could co-occur during a spatial task (Kita et al., 2017). In this study, our goal is not to determine which gesture function is predominant. We theorized that each function of gesture might be the reason why individuals gesture during spatial communication.

Research with children from a wide age range suggests that gestures reveal earlier development across many domains. For instance, Özçalışkan and Goldin-Meadow (2009) longitudinally measured the gestures and how much it would contribute to the language development of infants aged between 14- and 34-month-olds. At 14 months, infants use more gestures than speech. Children's communicative act, gesture, and noun plus gesture increased over time. At 18-month-old, all children were able to combine nouns with gestures (e.g., pointing a cookie while saying "eat") even though they were less likely to combine nouns with predicates. Before noun + predicate combinations infants use gesture speech combinations. A related study (Özçalışkan & Goldin-Meadow, 2011) showed that children's gesture production decreased slightly at 26-month-old, but their noun predicate combination increased (see Iverson and Goldin-Meadow, (2005) for converging evidence for younger infants). Furthermore, Özçalışkan and Goldin-

Meadow (2011) found that at 26-month-old, children conveyed different and more complex meanings in their gestures. These findings show a transition from gesture to speech and suggest that visual modality expressions precede spoken language expressions. Children use gestures more frequently for newly acquired expressions, when they fully develop the skill, their gesture production decreases.

Other work with preschoolers also showed that gestures used with speech facilitate meaning by conveying additional information when children communicate about events. For example, Göksun et al. (2010) investigated how preschool children express caused-motion event descriptions in speech and gesture. Children observed an event and were asked to describe what happened. Children caused-motion event expressions in speech and gesture were measured. They found that older children used more supplementary and pointing gestures. Also, older children used supplementary gestures for more complex sentences that conveyed both instrument and direction. However, younger children produced noncausal, less complex sentences and used location gestures for both goal and action. These findings suggest that children use gestures to explain caused-motion events and it increases the descriptions informativeness. Similarly, another corpus study (Furman et al., 2014) investigated the descriptions of caused-motion events with 12- 36-month-old children. They found that Turkish-speaking children used supplementary gestures when describing caused-motion events, especially in the form of iconic and pointing gestures. For example, children express caused-motion in speech as "poured there" and gesture to the goal of the action (e.g., the carpet) with an index finger point. These results demonstrate that children integrated gesture with speech in their early language development.

More importantly for present purposes, children frequently produce gestures to communicate spatial meanings. Sekine (2009) asked 4-, 5-, and 6-year-old children to describe their way to school, and they investigated children's gesture production longitudinally at 3 different times. At first, children mostly described the route with speech plus gesture. When the content of speech plus gesture was examined at an early time point, they did not informatively convey spatial information. Children mostly use non-spatial uninformative gestures at earlier ages. However, children's frequency of informative route descriptions in speech and gesture increased with age. When their speech conveyed some spatial information, they could also use gestures to enhance the informativeness of the descriptions. Finally, when children's informative descriptions in speech increased, their gesture use frequency relatively decreased. Children become able to describe the route direction better in speech, thus they use less gestures to increase their informativeness. Similar to the earlier work, children used more gestures earlier in their spatial language acquisition. However, with time children became more competent in expressing space in speech. Thus, their gesture production decreased.

In another study, Sauter et al. (2012) asked children aged between 8 and 10 to describe the locations of hidden objects. They found that 8-year-old children used fewer spatial terms than 10-year-old-children. In a follow up study, when children were encouraged to produce gestures, children frequently conveyed the spatial information missing from the speech by using their gestures. These results showed that children can use gestures as an additional tool in their spatial descriptions. Especially, when children use fewer spatial terms, gestures convey specific information about the location.

Finally, in a recent study Karadöller and colleagues (2021, under review) asked whether or not gestures reveal earlier expressions for left-right spatial language production. The study investigated left-right spatial language and gesture production in 8-year-old children and adults. Participants described a target spatial relations picture among 4 pictures that present various spatial relations. The study found that 8-year-old children did not produce informative descriptions of left-right spatial relations as frequently as adults. For example, children used under-informative general terms such as; next to, side etc. When they investigated descriptions in speech with gestures, they found that the frequency of informative descriptions increased for both children and adults. However, there were still developmental differences between children and adults in the frequency of informative descriptions in speech plus gesture. These results suggest that children can use gestures as an expressional tool in their descriptions. Gestures revealed earlier expressions for left-right spatial relations by conveying additional information into the speech. However, these findings also show that lateral viewpoint dependent relations (left-right) are particularly challenging, since, even with gestures children were not adult-like. This is possibly because they are symmetrical and (unlike front-behind) lack distinguishing features such as visibility or occlusion.

Summarizing, in many aspects of language development children rely on multimodal expressions to convey more information than speech alone. For instance, infants combine their first words with gestures (Özçalışkan & Golden-Meadow, 2009; 2011). Children also use gestures for describing caused-motion events (Furman et al., 2014; Göksun et al., 2010), routes (Sauter et al., 2012; Sekine 2009) and lateral viewpoint dependent relations (Karadöller et al., 2021, under review). Furthermore, while children's speech production increases, they tend to use less descriptions consisting of under-informative speech plus gesture. Thus, gestures seem to have a transition role in language development. When and how gestures have this transition role is still not fully known, especially in spatial descriptions that vary in their complexity.

2. 5. Present Study

There are limited studies investigating when and how children use gestures during their spatial descriptions. The previous literature provides evidence that gestures reveal earlier development for some spatial descriptions. That is, children frequently use gestures together with descriptions that are under-informative in speech. However, this is the case for the most complex spatial relations (lateral) that are acquired latest in development (Karadöller et al., 2021, under review). It is not known if they use gestures with under-informative descriptions for spatial relations that are acquired earlier in development such as topological and viewpoint dependent sagittal spatial relations. Furthermore, within those spatial relations that are acquired earlier, are there differences in the use of under-informative speech plus gesture combinations? Finally, when speech and gesture are both considered, do developmental differences between adults and children diminish or disappear completely?

To address these questions, we asked participants to describe pictures of various spatial relations to another person. Target pictures included topological and viewpoint dependent sagittal spatial relations. We looked at the frequency of informative spatial expressions they convey in speech, the frequency of spatial expressions that become informative when gesture is considered, and the total frequency of informative spatial expressions in speech and speech plus gestures.

2. 6. Predictions

For the speech only, we are expecting to see a developmental order of spatial language acquisition, as seen in prior work. Children are expected to produce informative spatial expressions more frequently for topological relations than viewpoint dependent sagittal relations in their speech. Adults are expected to produce informative spatial expressions equally frequently for both topological relations and viewpoint dependent sagittal relations because we assume that sagittal spatial relations will not be difficult for adults. We are not expecting an age difference for the topological spatial relations. Adults and children are expected to produce informative spatial expressions equally frequently. We expect age differences for the viewpoint dependent sagittal relations. Adults are expected to produce informative expressions more frequently than children.

For speech plus gesture, children should produce descriptions that become informative when gestures are considered more frequently than adults. Also, children should produce descriptions that become informative when gestures are considered more frequently for viewpoint dependent sagittal relations than topological relations. The topological spatial relations are easier than the sagittal spatial relations thus, we can expect children will already be informative in their speech. Also, we are expecting adults to produce spatial descriptions that become informative when gestures are considered equally frequently for viewpoint dependent sagittal and topological spatial relations.

Finally, when we consider gestures as an additional expressive tool for conveying spatial relations, children might produce informative spatial expressions as frequently as adults for the viewpoint dependent sagittal relations as well as topological relations. Thus, the developmental differences between children and adults might disappear with children's multimodal expressions.

CHAPTER 3

METHODS

The procedures used in this study were approved by The Ethics Review Board of the Radboud University, Nijmegen, and the Survey and Research Commission of the Republic of Turkey Ministry of National Education.

3. 1. Participants

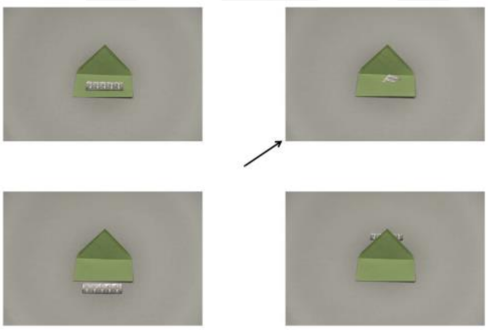
Participants consisted of 24 child (14 female; mean age = 8;6, age-range = 6;7 – 9;5) and 23 adult (14 female; mean age: 35;9, age-range = 19;8 – 50) hearing monolingual Turkish speakers. One child and two adults were excluded from the study because they were bilingual. Also, data from 2 children and 2 adults were excluded because they did not describe the target picture in most of the trials.

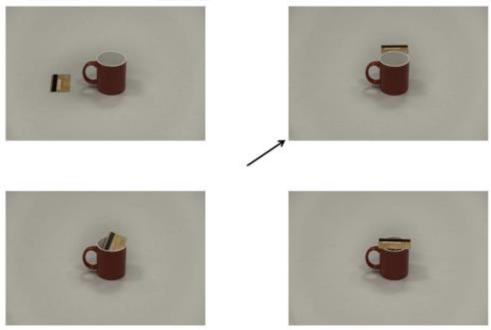
3. 2. Materials

Stimuli consisted of 84 displays (see Figure 2) of 4 pictures. Each picture within a display showed different spatial relations of the same two objects. The ground objects (e.g., envelope, mug) were placed in the center and the figure objects (e.g., pills, credit card) were placed in different locations with respect to the ground objects. Figure and ground objects did not have intrinsic sides (e.g., a teddy bear has an intrinsic front side but a mug does not). The target picture in the display was indicated with an arrow. The experimental displays (*n* = 56) showed topological (*n* = 28) and viewpoint dependent sagittal (*n* = 28) spatial relations of two objects (e.g., pills *in* the envelope). The other viewpoint dependent lateral displays (*n* = 28) remained as filler. In half of the experimental displays, one non-target picture depicted a contrastive spatial configuration from the same spatial relation category.

For instance, if the target picture is “pill *in* the envelope”, the contrast picture is “pill *on* the envelope” (see Figure 3 for contrast and non-contrast stimuli example). In the other half of the experimental displays, only the target picture depicted sagittal or topological relations and there were no contrastive spatial relations. For instance, if the target picture was “credit card *behind* a mug”, there was no other picture from the sagittal category. Other pictures comprised various types of spatial relations other than the same category.

Figure 3
Contrast (a) and non-contrast (b) experimental displays.

a 

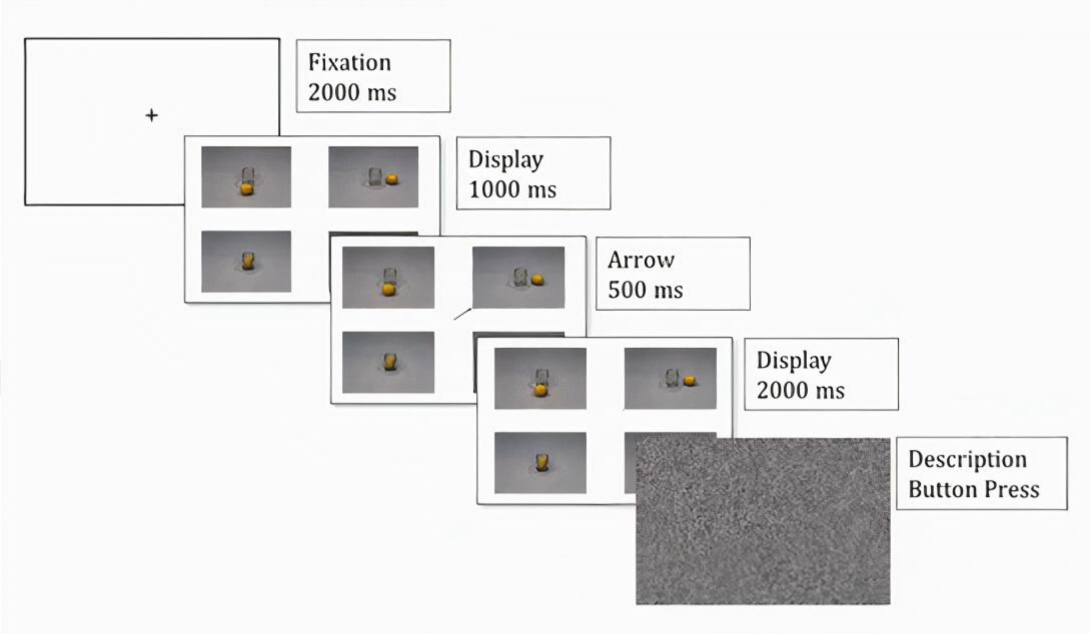
b 

In the stimuli list, each figure object was presented only once. We used the same ground objects 4 times. However, they were presented with different figure objects each time. For instance, the ground object “envelope” is represented with pills in one trial, and the same object represented with a metal key in another trial. In other words, the same two objects are never presented together for a different target spatial configuration. Also, each participant saw the displays in a different random order. The location of individual pictures within displays was also randomized.

3. 3. Procedure

During the experiment, participants first saw a fixation cross (2000 ms). After the fixation cross, a display with 4 pictures was presented (1000 ms). An arrow became visible for a short time (500 ms) to specify the target picture and then disappeared. The display with 4 pictures remained (2000 ms) on the screen. Then the visual white noise appeared on the screen. Participants were instructed to describe the target picture during the visual white noise screen. Participants knew that the addressee had the same 4 pictures but the pictures were arranged in a different order and shown without the arrow on a tablet. They were informed that the addressee would select the picture on the tablet according to their descriptions. The addressee pretended to choose a picture on the tablet based on the participant’s descriptions. After the descriptions ended, participants pressed the ENTER key on the keyboard to move on to the next trial.

Figure 4
Timeline of a trial in the description task.



At the beginning of the experiment, participants saw three practice trials which consisted of 3 displays that were not present during the experiment. All participants saw the same 3 displays as the practice trials. These trials aimed to introduce the general principles of the experiment. The addressee explained the practice and the test trials. If participants had difficulty understanding the task, the experimenter repeated the practice trials.

The addressee gave no feedback to the participants and stayed neutral throughout the experiment. The addressee did not say if the answer was correct or not, but she pretended to find the picture that participants described (e.g., “Buldum.” “I found it.”). When the participant failed to give enough information about the location, the addressee only asked the location of the figure object once (e.g., “Peynir nerede?” Where is the cheese?). If the participant still had difficulty giving enough information, the addressee did not question further and pretended to find the picture. Additionally, participants were not instructed to gesture and did not know the experiment measured their gestures. Therefore, all gestures (if any) were spontaneously produced.

3. 4. Annotation and Coding

All descriptions that participants produced for the target picture in the experiment were annotated for speech and gesture. Annotations, transcriptions, and coding done in ELAN (Version 4) (Lausberg & Sloetjes, 2009; Wittenburg et al., 2006). Annotations, transcriptions, and coding of speech and gesture done by the thesis author who is a native speaker of Turkish.

3. 4. 1. Speech Coding Annotation and Coding

First of all, we transcribed the participants' descriptions. Second, we coded participants' speech for whether or not they used spatial encoding in their descriptions. The descriptions that did not linguistically encode spatial relations were coded as missing. If they linguistically encoded spatial relations, we coded whether or not it was correct. We obtained three general categories:

(1) *Correct Spatial Descriptions*: This category consists of correct spatial linguistic encodings equivalent to the particular spatial relations. Any description that correctly expresses a particular spatial relation can be defined as a correct spatial description. For more detailed information and examples, please see figure 5a and figure 5b.

(2) *Incorrect Spatial Descriptions*: This category consists of incorrect description about a particular spatial relation. For instance, using the spatial

term behind for front spatial relation would be considered as an incorrect spatial description. For more detailed information and an example, please see figure 5c.

(3) *Missing Spatial Descriptions*: This category consists of descriptions that fail to provide any spatial location information. For more detailed information and an example, please see figure 5d.

Figure 5
Example of Turkish spatial descriptions; (a) correct specific spatial description, (b) correct general spatial description, (c) incorrect spatial description, (d) missing spatial description

(a)	kupa-nın	arka-sın-da	kredi kartı	var.
	mug-GEN	behind-POSS-LOC	credit card	there.is
	GROUND	SPATIAL RELATION	FIGURE	

‘There is a credit card behind the mug.’

(b)	kupa-nın	yan-ın-da	kredi kartı	var.
	mug-GEN	side-POSS-LOC	credit card	there.is
	GROUND	SPATIAL RELATION	FIGURE	

‘There is a credit card next to the mug.’

(c)	kupa-nın	ön-ün-de	kredi kartı	var

	mug-GEN	front-POSS-LOC	credit card	there.is
	GROUND	SPATIAL RELATION	FIGURE	

‘There is a credit card in front of the mug.’

(d)	kupa	var.	kredi kartı	var.
	mug	there.is	credit card	there.is
	GROUND		FIGURE	

‘There is a mug. There is a credit card.’

As a next step, we grouped the participants' spatial descriptions into two categories based on spatial terms that were used during descriptions: informative spatial expressions and under-informative spatial expressions. This distinction is based on whether or not the descriptions of the target spatial relation is uniquely identified.

(1) *Informative Spatial Expressions*: Informative spatial expressions are the spatial descriptions that include specific spatial nouns. Those specific spatial nouns are içinde ‘in’, üstünde ‘on’, önünde ‘front’, and arkasında ‘behind’. For occlusion spatial relation, the spatial noun “behind”, for visibility spatial relation, the spatial noun “front”, for containment spatial relation, the spatial noun “in”, and for support spatial relation spatial noun “on” count as informative specific spatial terms.[1]

[1] In 4 displays (“tray ball on”, “tray candle small on”, “tray funnel on”, “tray string on”), there was no difference between “in” and “on” spatial relation because of the feature of the ground object “tray”. We coded both “in” and “on” responses as correct for those 4 tray ground displays.

(2) *Under-Informative Spatial Expressions:* Under-informative spatial expression includes three categories.

(2.a) *General Spatial Expressions:* The spatial expression in this category provides general information about the object's location but fails to provide the exact location. For sagittal spatial relations such expressions included general spatial nouns *yanında* "next to" and *yanı* "side". For topological spatial relations such expressions included the spatial noun *ortası* "middle".

(2.b) *Other Spatial Expressions*: Spatial expressions that included neither specific nor general spatial terms about the location such as; yukarısında 'above', karşısında 'across'. These spatial terms somehow describe the location, but their spatial references were ambiguous.

(2.c) *Missing Spatial Expressions*: Spatial expressions that fail to provide any information about the spatial location. This category did not contain any spatial terms.

3. 4. 2. Gesture Annotation and Coding

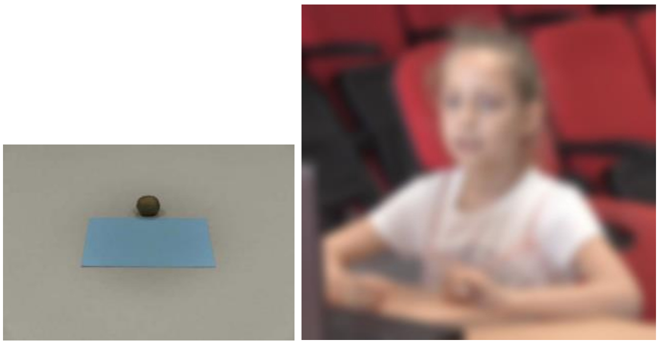
We coded the spontaneous spatial gestures that convey information about the spatial relations between the figure and ground objects. The gesture without additional spatial information, such as, beat gestures, were not included in the coding. Additionally, gestures that represented only the shape of the objects were not counted as spatial gestures. Those types of gestures that provide information about the shape, but they fail to provide information about the location of objects. We coded gestures separately for the figure and ground objects. If participants used only figure gestures, we coded them as spatial gestures. However, if the participant used only ground gestures, we did not include them into coding. Only ground gestures did not convey enough information about the object's spatial location and therefore, they did not to provide additional information into the speech. In the gesture coding, we categorized gestures into two categories.

(1) *Pointing gestures*: This category contains a direct finger or palm pointing the place of figure and/or ground object (See figure 7).

(2) *Placement gestures*: This category contains general or specific placement of the figure and/or ground objects. General placement is placing of the figure and/or ground object into the gesture space with a neutral hand shape. Specific placement is placing the figure and/or ground object into the gesture space with a specific hand shape about the objects (See figure 5).

Figure 6

Informative spatial expression in the speech that uses a specific spatial noun "behind" that is accompanied by a specific placement gesture.

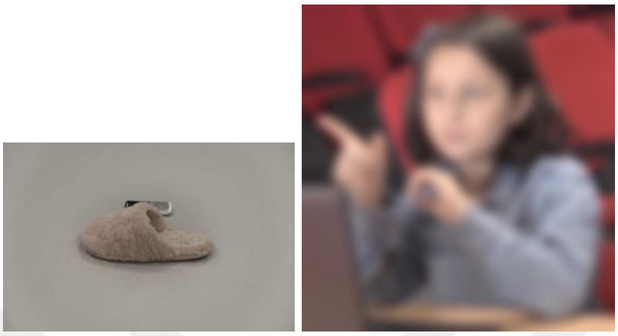


Bir tane mavi bir bez var, bir tane de kivi var onun arkasında.

'There is a blue swab, there is a kiwi behind of it'

Figure 7

Spatial expressions informative when gesture considered that uses a general spatial noun "side" that is accompanied by a pointing gesture.



Bir tane terlik var, bu tarafında da bir telefon var.

'There is a slipper, there is a phone at this side of it'

3. 4. 3. Speech Plus Gesture Annotation and Coding

We assessed under which conditions spatial expressions and gestures increase the frequency of informative spatial expressions of the speech. We created the multimodally informative categories by considering what was conveyed in the speech and gesture.

(1) *Spatial Expressions Informative in Speech*: This category only consists of descriptions with specific spatial terms in, on, front, and behind. Those spatial terms are considered informative regardless of whether or not accompanied by spatial gestures. Some of these descriptions also include complimentary gestures. However, gestures did not add extra informativeness because the speech was already informative (see Figure 6).

(2) *Spatial Expressions Informative When Gesture Considered*: This category involves the descriptions with general spatial terms next to, side, middle in speech and together with supplementary spatial gestures. If under-

informative general spatial terms accompanied by a spatial gesture, the total description is considered informative. In this category, spatial gestures convey additional informativeness because the speech fails to give a specific location (see Figure 7).

(3) *Under-Informative Spatial Expressions Even with Gesture*: This category involves the descriptions with other spatial terms like ahead, across and missing spatial descriptions in speech and together with spatial gestures. If under-informative other spatial terms and missing spatial descriptions are accompanied by a spatial gesture, the total description is still considered under-informative because the description in speech is ambiguous.

CHAPTER 4

RESULTS

4. 1. Descriptive Statistics

As a first step, we checked the frequency of different types of spatial descriptions (specific noun, general noun, other noun, and missing) that were accompanied with gesture vs. those without a gesture. Table 1 shows the frequency of different types of spatial descriptions with and without a gesture across topological spatial relations and viewpoint dependent sagittal spatial relations for in children and adults.

Table 1
Frequency of Different Types of Spatial Descriptions With and Without Gesture Production Across Adults and Children and Two Spatial Relations Types

	Spatial Description Type				
	Specific Noun	General Noun	Other Noun	Missing	Total
Adults					
Topological					
Gesture	106	0	0	2	108
No Gesture	467	0	0	8	475
Sagittal					
Gesture	128	15	5	1	149
No Gesture	309	29	0	3	341
Child					
Topological					
Gesture	161	3	0	4	168
No Gesture	383	0	0	5	388
Sagittal					
Gesture	173	118	2	3	296
No Gesture	208	42	0	11	261
Total	1935	207	7	37	2186

4. 2. Inferential Statistics

Generalized binomial linear mixed-effects model (*glmer*) analysis with random intercepts for subjects and items was used to analyze the data. This analysis was suitable for our design because it allowed us to consider the random variability from different subjects and items. All models were fitted with the *lme4* package (version 3.3.3; Brown, 2021) in R (R Core Team, 2017). We used the optimizer *bobyqa* in the speech plus gesture analysis (Powell, 2009). Also, we use the *ggplot2* package (Wickham, 2016) for data visualization.

4. 2. 1. Data Exclusion

Before the analyses, we excluded the filler lateral viewpoint dependent spatial relations left-right stimuli. We continued our analysis only with the experimental sagittal viewpoint dependent and topological spatial relations. Also, “shoe sock on” display was excluded from the analysis. This display was a contrast stimulus, and the “in” and “on” pictures resembled each other a lot. In other words, it was likely that participants falsely perceived the “shoe sock on” spatial relation as “shoe sock in”. Lastly, before we started analysis, we excluded the incorrect spatial encoding responses which is %16.08 of the total responses of the experimental stimuli. We conducted the statistical analysis with the correct and missing spatial encoding responses.

4. 2. 2. Preliminary Analyses

As preliminary analyses, we investigated the frequency of informative spatial expressions for two different contrast types. Our dependent variable was binary values for the presence of the frequency of the informative spatial expressions at the item level (1 = present, 0 = absent). Fixed effects of age (children vs. adults), spatial relations (topological vs. viewpoint dependent sagittal), and stimuli contrast type (contrast vs non-contrast) were tested with sum-to-zero contrasts (for age: -½ adults, ½ children, for spatial relations: -½ topological, ½ sagittal, for stimuli contrast type: -½ contrast, ½ no-contrast). The model also included random intercepts for subjects and items. There was no significant difference between contrast and no-contrast stimuli type's frequency of informative spatial expressions differences for the age groups and the spatial relations. In other words, participants produced informative spatial expressions equally frequently for two contrast types in each spatial relation. Thus, we collapsed data from contrast and no-contrast displays for the main analyses.

Table 2

Fixed effect estimates from the glmer model for the frequency of informative spatial expressions for stimuli contrast type.

Effect	Estimate	SE	*z*-value	*p*-value
Intercept	3.86	0.39	9.78	<.001
Age (Adults vs Children)	-0.58	0.75	-0.77	0.442
Spatial Relations (Topological vs. Sagittal)	3.64	0.30	12.18	<.001
Contrast Type (Contrast vs. No-contrast)	0.42	0.25	1.66	**.096**
Age (Adults vs Children) * Spatial Relations (Topological vs. Sagittal)	1.20	0.59	2.03	.096
Age (Adults vs Children) * Contrast Type (Contrast vs No-Contrast)	0.07	0.51	0.15	**.877**
Spatial Relations (Topological vs. Sagittal) * Contrast Type (Contrast vs. No-contrast)	0.47	0.51	0.93	0.350
Age (Adults vs Children) * Spatial Relations (Topological vs. Sagittal) *Contrast Type (Contrast vs No-Contrast)	0.60	1.01	0.59	**.555**

Formula in R: Speech Informativeness ~ Age * Spatial Relations * Contrast Type + (1|subject) + (1|Stimuli_content)

Note. p-values that are critical to the analysis are in boldface

As a second preliminary analysis, we investigated the frequency of informative spatial expressions differences for viewpoint dependent sagittal spatial relations front and behind. In our main analyses, we investigated the viewpoint dependent sagittal spatial relations front and behind as a one category. However, before the main analyses, we wanted to examine if there was an asymmetry between front and behind as the literature suggested. Our dependent variable was binary values for the presence of the frequency of the informative spatial expressions at the item level (1 = present, 0 = absent). Fixed effects viewpoint dependent sagittal spatial relations (front vs. behind), were tested with sum-to-zero contrasts (for age: -½ adults, for viewpoint dependent sagittal spatial relations: -½ behind, ½ front). The model also included random intercepts for subjects and items. There was no significant difference in front and behind spatial relations' frequency of informative spatial expression. In other words, we did not find an asymmetry between front and behind.

Table 3

Fixed effect estimates from the glmer model for frequency of informative spatial expressions for front and behind

Effect	Estimate	SE	*z*-value	*p*-value
Intercept	2.54	0.65	3.89	<.001
Age (adults vs children)	-1.70	1.24	-1.37	0.170
Viewpoint Dependent Sagittal Spatial Relation (Front vs Behind)	-0.18	0.23	-0.75	.449
Age (adults vs children) * Viewpoint Dependent Sagittal Spatial Relation (Front vs Behind)	-0.41	0.48	-0.86	.391

Formula in R: Speech Informativeness ~ Age*Viewpoint Dependent Sagittal Spatial Relation + (1|subject) + (1|Stimulus_content)

4. 2. 3. Spatial Expressions Informative in Speech

In our main analyses, first we investigated the frequency of informative spatial expression based on speech only. This analysis compared the frequency of informative spatial expressions in speech across age two groups and two spatial relations. Our dependent variable was binary values for the presence of frequency of informative spatial expressions in the speech at the item level (1 = present, 0 = absent). Fixed effects of age (children vs. adults) and spatial relations (topological vs. viewpoint dependent sagittal) were tested with sum-to-zero contrasts (for age: -½ adults, ½ children, for spatial relations: -½ topological, ½ sagittal). The model also included random intercepts for subjects and items.

Figure 8

Proportion of informative spatial expressions across age groups and two spatial relations in speech

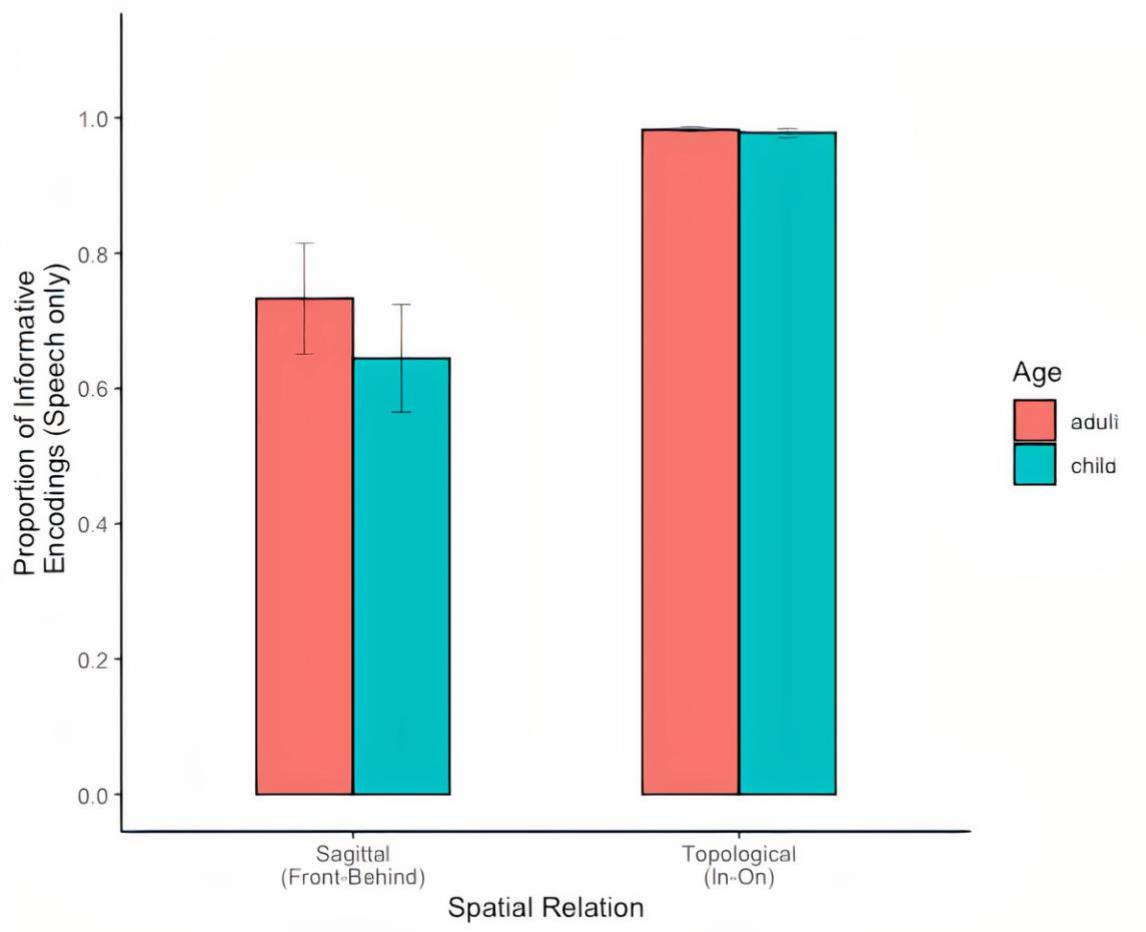


Table 4

Fixed effect estimates from the glmer model for the frequency of informative spatial expressions in speech

Effect	Estimate	SE	*z*-value	*p*-value
Intercept	3.84	0.39	9.74	<.000
Age (Adults vs. Children)	-0.59	-0.59	-0.79	.429
Spatial Relations (Topological vs. Sagittal)	3.62	0.29	12.36	<.000
Spatial Relations (Topological vs. Sagittal) *Age (Adults vs. Children)	1.14	0.57	1.98	.047

Formula in R: Speech Informativeness ~ Age * Spatial Relations + (1|subject) + (1|Stimuli_content)

For spatial expressions informative in speech, we expected a developmental order of spatial language acquisition. Children were expected to produce informative spatial expressions more frequently for topological relations than viewpoint dependent sagittal relations in their speech. Adults were expected to produce informative spatial expressions equally frequently for both topological relations and viewpoint dependent sagittal relations. As expected, here was a significant difference between topological and viewpoint dependent sagittal spatial relations: participants produced informative expressions more frequently for topological spatial relations than viewpoint dependent sagittal spatial relations. However, this was qualified by a significant interaction between participant's age (adult vs child) and spatial relation type (topological vs viewpoint dependent sagittal): for viewpoint dependent sagittal spatial relations, children were less frequently informative than adults. For topological spatial relations, children and adults produced informative expressions equally frequently.

4. 2. 4. Spatial Expressions Informative When Gestures Considered

Second, we tested the frequency of spatial expressions that become informative when gestures considered across children and adults and spatial relations. As a reminder, this category consisted of descriptions with general spatial terms next to, side, middle in speech and together with supplementary spatial gestures. Unlike the previous models, in this analysis the model failed to converge because of an error of degenerate Hessian with 1 negative eigenvalues. We conducted two sets of analyses to test our predictions. In the first set of analysis, we tested the frequency of informative descriptions that become informative when gestures considered differences across spatial relations types for children and adults. Our dependent variable was binary values for the presence of the informative spatial descriptions when gestures were considered at the item level (1 = present, 0 = absent). To test this, we conducted two separate models for each spatial relation. For each model, the fixed effect of age (children vs. adults) was tested with sum-to-zero contrasts (for age: -½ adults, ½ children). The models also included random intercepts for subjects and items.

Figure 9

Proportion of informative spatial expressions informative when gestures considered across age groups and two spatial relations

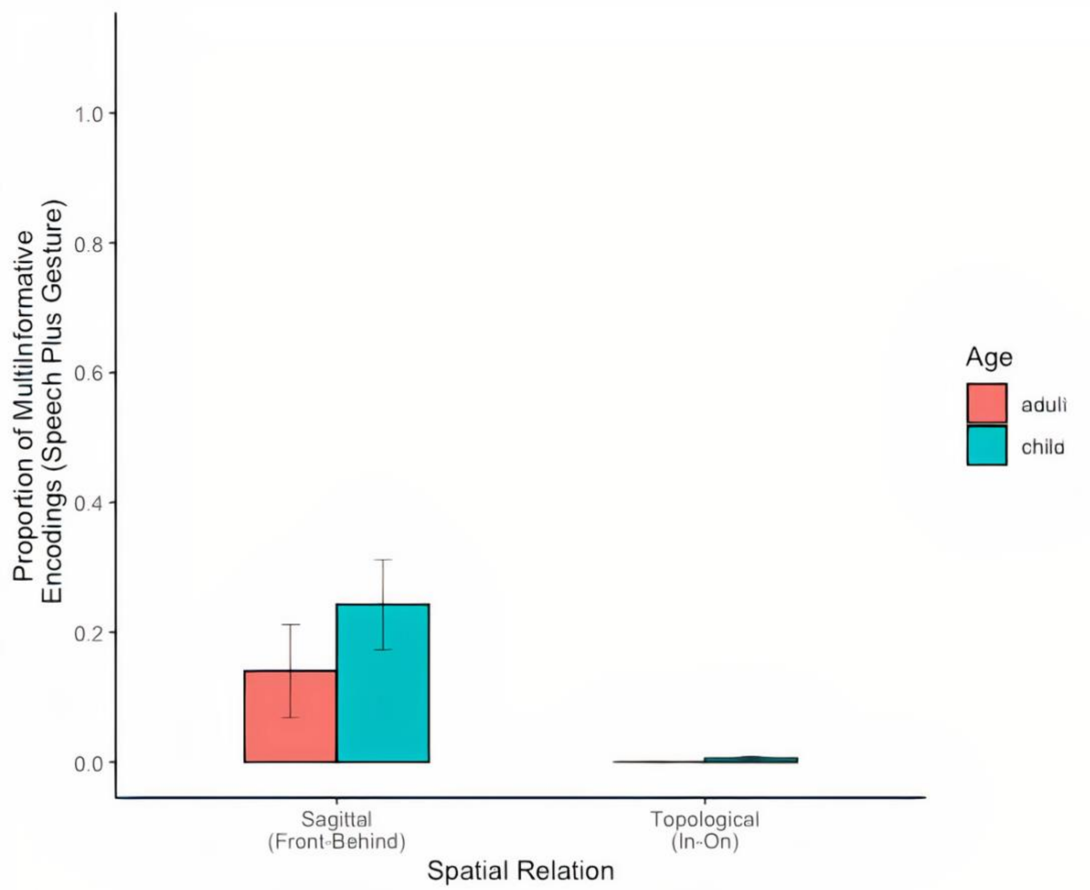


Table 5

Fixed effect estimates from the glmer model for the frequency informative spatial expressions when gestures considered for two spatial relations

Effect	Estimate	SE	*z*-value	*p*-value
Topological				
Intercept	-24.52	836.09	-0.03	.977
Age (Adults vs. Children)	19.31	836.09	0.02	.982
Sagittal				
Intercept	-7.87	1.58	-4.98	<.000
Age (Adults vs. Children)	3.47	1.71	2.02	<.042

Formula in R: Multimodality Informativeness ~ Age + (1|subject) + (1|Stimuli_content)

For topological spatial expressions that become informative when gesture considered, we expected children and adults to produce spatial expressions that become informative when gesture is considered equally frequently. However, for sagittal spatial relations, we are predicting that children will produce spatial expressions that become informative when gesture is considered more frequently than adults. In line with these predictions, for topological spatial relations, there were no significant differences between adults and children for the frequency of spatial expressions that become informative when gestures were considered. However, for viewpoint dependent sagittal spatial relations, there were significant differences between children and adults. Children produced the spatial expressions that were informative when gestures are considered more frequently than adults.

In the second set of analyses, we tested the frequency of informative description when gestures considered developmental differences of age groups for viewpoint dependent sagittal and topological spatial relations. Our dependent variable was binary values for the presence of the informative spatial descriptions when gestures were considered at the item level (1 = present, 0 = absent). To test this, we conducted two separate models for adults and children. For each model, the fixed effect of spatial relations (sagittal vs. topological) was tested with sum-to-zero contrasts (for age: -½ topological, ½ sagittal). The models also included random intercepts for subjects and items.

Table 6
Fixed effect estimates from the glmer model for the frequency informative spatial expressions when gestures considered for two age groups

Effect	Estimate	SE	*z*-value	*p*-value
Adult				
Intercept	-12.50	2.80	-4.46	<.000
Spatial Relation (Sagittal vs. Topological)	-28.38	1024.00	-0.02	.978
Child				
Intercept	-2.93	0.80	-3.66	<.000
Spatial Relation (Sagittal vs. Topological)	-5.21	0.66	-7.84	<.000

Formula in R: Multimodality Informativeness ~ Spatial Relation + (1|subject) + (1|Stimuli_content)

We expected that children should produce descriptions that become informative when gestures are considered more frequently for viewpoint dependent sagittal relations than topological relations. For adults, we are expecting them to produce spatial descriptions that become informative when gestures are considered equally frequently for viewpoint dependent sagittal spatial relation and topological spatial relation. As expected, for adult age group, there were no significant differences between viewpoint dependent sagittal and topological spatial relations for the frequency of spatial expressions that become informative when gestures were considered. However, for children age group, there were significant differences between viewpoint dependent sagittal and topological spatial relations for the frequency of the spatial expressions that were informative when gestures are considered. Children produced descriptions that become informative when gestures are considered more frequently for the viewpoint dependent sagittal spatial relations than for topological relations.

4. 2. 5. All Informative Spatial Expressions

Lastly, we tested whether the frequency of informative spatial expression would increase when gesture was considered together with speech. As a reminder, informative expressions in this analysis consisted of all informative descriptions in speech and the spatial expressions that become informative when gestures were considered. Our dependent variable was binary values for the presence of informative expressions in speech plus gesture at the item level (1 = present, 0 = absent). Fixed effects of age (children vs. adults) and spatial relations (topological vs. viewpoint dependent sagittal) were tested with sum-to-zero contrasts (for Age: -½ adults, ½ children, for Spatial relations: -½ topological, ½ sagittal). The model also included random intercepts for subjects and items.

Figure 10

Proportion of informative spatial expressions across age groups for two spatial relations in speech plus gesture.

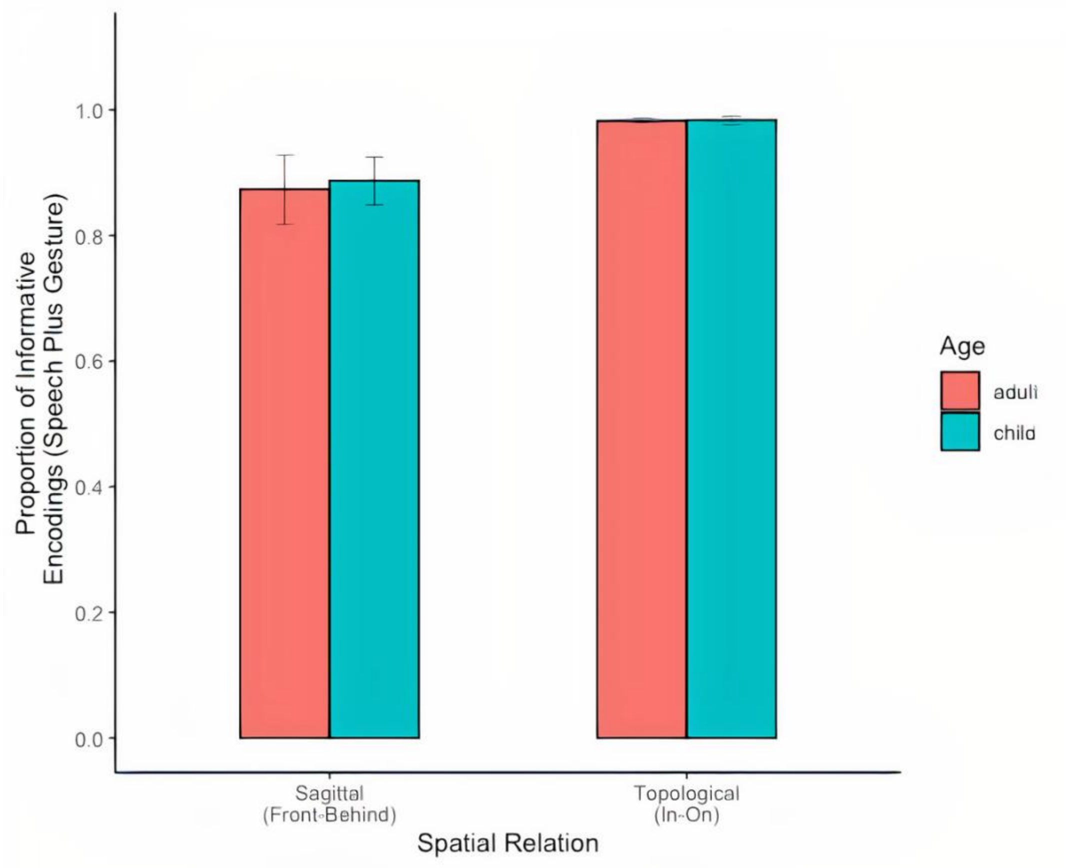


Table 7

Fixed effect estimates from the glmer model for the frequency of informative spatial expressions in speech plus gestures

Effect	Estimate	SE	*z*-value	*p*-value
Intercept	4.14	0.32	12.74	<.000
Age (Adults vs. Children)	0.01	0.57	0.03	.977
Spatial Relations (Topological vs. Sagittal)	2.14	0.29	0.30	<.000
Spatial Relations (Topological vs. Sagittal) *Age (Adults vs. Children)	0.23	0.56	0.56	.673

Formula in R: Speech Plus Gesture Informativeness ~ Age * Spatial Relations + (1| Subject) + (1| Stimuli_content)

Finally, when all the informative spatial expressions in speech plus gesture considered together, we are expecting the developmental differences for sagittal spatial relations to disappear completely. When we looked at the speech plus gestures, the frequency of informative spatial expressions differed across spatial relations: participants produced informative spatial expressions more frequently for topological spatial relations than viewpoint dependent sagittal spatial relations. However, there was no longer a significant interaction between age and spatial relations. That is, children's frequency of informative spatial expression of sagittal spatial relations was not significantly less frequently than adults. Thus, the frequency of children's informative spatial descriptions became adult like with gestures.

CHAPTER 5

DISCUSSION

5. 1. General Discussion

There is a growing body of literature that examines when and how children use gestures for their spatial descriptions. Previous research has found that children frequently use gestures together with descriptions that are under-informative in speech for the most complex (lateral) spatial relations (Karadöller et al., 2021, under review). However, we did not know if multimodal spatial expressions are sensitive to the complexity of spatial relations and that these patterns would generalize to the spatial relations acquired earlier in development, such as topological and viewpoint dependent sagittal relations. Furthermore, we did not know if the developmental differences between children and adults would diminish or disappear completely when speech and gestures are considered together.

This study investigated those research questions in three steps. First, we looked at when and how participants expressed spatial relations based on their speech only. We found developmental differences between the expressions of two spatial relations that varied on their complexity. Children and adults produced informative spatial expressions equally frequently for topological spatial relations. However, children produced informative spatial expressions less frequently than adults for viewpoint dependent sagittal spatial relations. In the second analysis, we looked at how frequently children and adults produce spatial expressions that become informative when gestures are considered. Children produced spatial expressions that became informative when gestures are considered more frequently than adults. Also, children produced more spatial expressions that became informative when gestures are considered for viewpoint dependent sagittal spatial relations than topological relations. Finally, we looked at the developmental differences in the informative spatial expressions between children and adults for all informative spatial expressions in speech and in speech plus gesture. When we considered gestures as an additional expressive tool for conveying spatial relations, children produced informative spatial expressions as frequently as adults for both topological relations and viewpoint dependent spatial relations. The developmental differences between children and adults disappeared with children's multimodal expressions. We discuss our findings in more detail below.

5. 2. Developmental Order of Spatial Language Acquisition

First, we looked at when and how children's and adults' frequency of informative descriptions differ in speech. The frequency of informative spatial expressions differed between adults and children across two different spatial relations conditions. Our speech results indicate that children and adults produced informative spatial expressions equally frequently for topological spatial relations. However, children produced informative spatial expression less frequently than adults for the viewpoint dependent sagittal spatial relations. Thus, there were developmental differences between topological and viewpoint dependent sagittal spatial relations. Previous studies suggest that topological spatial relations are acquired earlier than viewpoint dependent sagittal spatial relations (Bowerman & Choi, 2001; Johnston & Slobin, 1979). Our results confirmed these previous findings showing that there is a developmental order in the acquisition of spatial relations. This order might reflect the complexity of spatial relations (Clark, H., 1973). Children had less difficulty in earlier acquired topological spatial relations and they had more difficulty in for the viewpoint dependent sagittal spatial relations. Importantly, in previous work children began to express front and behind spatial relations at age 4 (Levine & Carey 1982; Johnston 1984), but we found that they still struggled in speech at age 8. More interestingly, adults also produced informative spatial expression less frequently in viewpoint dependent sagittal spatial relations than they did for topological spatial relations. Similar to children, also adults might have used under-informative general and other spatial terms for viewpoint dependent sagittal relations. These results underline the order of complexity of spatial relations. The difficulty remains challenging across the two age groups.

Previous studies have found an asymmetry between front and behind expressions across different languages (Grigoroglou et al., 2019; Johnston, 1984; Levine & Carey, 1982). As discussed above, children produced more behind terms than front terms. We investigated this asymmetry differences between the front and behind spatial relations as a preliminary analysis. We did not find an asymmetry between front and behind spatial relations expressions in children and adults. There might be several possible reasons for this result. First of all, we might need to consider the children's age. In our study, we worked with 8-year-old children. Previous studies recruited younger children; Johnston (1984) worked with 2- and 4-year-old, Levine and Carey (1982) worked with 2- and 3-year-old, and Grigoroglou et al. (2019) worked with 3- and 4-year-old children. Moreover, those studies suggest that children learn to express front and behind spatial relations at the age of 4. Our child participants could complete the development of asymmetric patterns between front and behind. However, it may not be the most logical explanation because Grigoroglou et al. (2019) also found asymmetry in their adult participants. Thus, our participant's age range is unlikely to be the reason why we did not find asymmetry between front and behind spatial relations.

A more likely explanation for this result might be the features of our materials. Our 4-picture stimulus displays consisted of two static objects and various spatial relations. In fact, the study (Grigoroglou et al., 2019) that found asymmetry used different set of stimuli which was motion events. In their stimuli, a figure object moved behind and front of a ground object. Moreover, they had two different occlusion conditions: bigger ground objects that fully occluded the figure objects and smaller ground objects that occluded the figure objects to a lesser extent. They found that the change in the occlusion was more noteworthy to mention than (the lack of) change in the visibility. In our cases, there was no change in visibility or occlusion, because we used static pictures instead of videos. Unlike Grigoroglou et al. (2019), we did not systematically manipulate change in occlusion, and the amount of occlusion or amount of visibility nor we had a case where everything was fully invisible. These different results suggest the importance of the materials in the spatial relations expression tasks. Thus, future research should take into consideration the motion and static spatial relations result differences.

5. 3. Gesture Reveals Earlier Development of Spatial Expressions

When we investigated how frequently children and adults produced spatial expressions that become informative when gestures are considered, we found that children produced more spatial expressions that were informative when gestures are considered for viewpoint dependent sagittal spatial relations than topological relations. In other words, children combined their under-informative speech with gestures more frequently for complex spatial relations. Children produced more gestures for the more recently acquired spatial relations. This is consistent with prior work showing that gestures reveal earlier development. For instance, infant studies showed that children combine their speech and gesture in early language development (Özçalışkan & Golden-Meadow, 2009, 2011). Children have limited vocabulary at an early age; therefore, they benefit from gestures for spatial expressions. However, while their vocabulary increases their gesture use decreases (Iverson and Goldin-Meadow, 2005; Özçalışkan & Golden-Meadow, 2009, 2011). Gradually, both speech and gestures take more complex forms. Gestures emerge as a precursor for vocabulary development and speech production. Similar patterns were found for spatial language development. According to Sekine’s (2009) findings, children’s gesture frequency decreased with development. As children grew older, they were able to express spatial relations more in speech and produced gestures less frequently. As a result, when children learn to express a relation in their speech, they may rely on gestures less frequently.

Our results confirmed that children express spatial relations with under-informatively in speech plus gestures during the language acquisition period, such as viewpoint dependent sagittal relations. In the sagittal spatial relations, children had difficulty in expressing the relations in speech. For that reason, they produced gestures to complete their expressions. However, participants did not only use supplementary gestures that conveyed additional information missing from under-informative spatial expressions. In our data, participants also produced complementary gestures that conveyed the same information as their informative spatial expressions. The proportion of no gesture response is 0.76 for adults and 0.58 for children. Children produced more gestures than adults for both their informative and under-informative spatial expressions. Furthermore, both adults (0.10) and children (0.13) produced gestures mostly for figure objects only. For the specific gesture types, adults mostly produced placement type of gestures (0.06). On the other hand, children mostly produced placement and pointing mixed type gestures (0.13). Besides, when children produced spatial expression in speech more informatively, they produced fewer spatial expressions that are informative when gestures are considered to express spatial relations. In topological spatial relations, children were already informative in speech so they produced fewer spatial expressions that are informative when gestures are considered.

In terms of the theoretical discussion regarding functions of gestures, our study cannot claim which function of gesture is more dominant in spatial relations. Besides, communicative and self-oriented functions are not mutually exclusive (Kita et al., 2017); therefore, both functions can drive gesture production. In our study, participants might have produced gestures by benefiting from both functions. Firstly, gestures' communicative function suggests that individuals produce gestures to convey their massage better (Golden-Meadow, 1999). In our study, participants described the spatial relations to an addressee. The addressee pretended to find the target picture on the tablet, and responded with a sentence such as “I found it”. The participants' task was to produce enough descriptions for the addressee. The addressee might have created a communication illusion for the participants. Thus, they might have produced gestures to describe the spatial relations better to the next person. Nevertheless, we did not measure the addressee’s perspective, and how much the addressee correctly identified the spatial relations. The aim of the study was not to measure the communicative results of gesture production. Future research may investigate the communicative function of gestures in locative spatial relations by manipulating the addressee’s perspective.

Self-oriented functions of gestures suggest that we produce gestures to regulate our mental states (Kita et al., 2017). The gesture for conceptualization hypothesis builds on the self-oriented function of gesture. This hypothesis suggests that gestures activate, manipulate, package and explore spatial motoric information (Kita et al., 2017). These aspects of gesture may have helped participants to find missing information. Spatial gestures practically depict the actual action. For instance, when producing the placement gestures, the participant pretends to put the objects in their actual locations. We found that children and adults used more gestures for more complex spatial relations. When their speech is not fully giving the information, gestures help participants to find missing information. This visual motivation creates an additional expression tool for children that are not as competent in their speech yet. That is to say, children can visually show the relations even if they cannot produce specific spatial terms. Verbal and iconic representation together create an easy descriptions perspective. Thus, gestures increase the frequency of informativeness of descriptions and reveal earlier competence.

These findings are consistent with the idea that visually motivated depictions in gesture provide an easier way to describe the target relations. Instead of using morphologically complex expressions, individuals map the relations onto placement or pointing gestures in an analogue way. In fact, recent work suggests that the visual modality of expression may modulate spatial language acquisition (Karadöller, 2022; Sümer, 2015). These kinds of expressions are prevalent in sign languages that depend on iconic expressions as well. For instance, Karadöller et al., (2021, under review) compared TID (Turkish Sign Language) signers and Turkish speaker children's viewpoint dependent lateral spatial relations expression. They found that TID signing children produced informative spatial descriptions more frequently than hearing children’s speech plus gesture spatial expressions. Even with iconic gestures, Turkish speaker children did not reach the frequency of informative descriptions of their signer peers. This evidence showed that direct mapping on the body coordination with a visually motivated iconic way may facilitate spatial expressions.

Nevertheless, the visual modality may not have an advantage across all types of locative spatial relations. For instance, Sümer et al. (2014) examined the viewpoint dependent sagittal and lateral spatial relations with locative pictures with TID signing and Turkish speaking participants. When they looked at the spatial expressions of two language groups, they found that for sagittal viewpoint dependent spatial relations, TID signing deaf children were not adult-like in their language strategies. However, Turkish speaking children produced spatial nouns as frequently as Turkish speaking adults. Furthermore, unlike their hearing peers TID signing children were more adult-like for lateral relations than sagittal spatial relations. Future research may compare TID signing children and their hearing peers' speech plus gesture descriptions to better understand how the visual modality of expressions and the complexity of the spatial relations jointly shape spatial language acquisition.

Furthermore, Karadöller et al., (2021) examined children with late TID exposure and their native signer peers for topological and viewpoint dependent lateral spatial relations expressions. Late signing children differed from native signing children in their language use for viewpoint dependent lateral relations, but they did not differ for topological spatial relations. The hindering effect of late sign language exposure changed based on the complexity of spatial relations. This result showed that even with a visually motivated language, the hindering effect of late sign language exposure persisted for more complex spatial relations expressions. Furthermore, Sümer and Özyürek (2020) investigated the TID signer and Turkish speaking children's locative topological spatial relations expressions. They did not find any differences between the two language groups for the frequency of informative spatial relations expression. Unlike more complex lateral relations, sign language and spoken language did not differ for less complex spatial relations. The sign language studies showed an interaction between the benefit of the visual modality of expression and spatial relations complexity. Visual depiction can increase the frequency of the spatial expressions. However, visual modality is not always an advantage as previous research suggests. Our results support the previous literature, visual depiction of spatial relations increases the frequency of informative spatial expression, yet it is not for all spatial relations that vary in their complexity.

5. 4. Developmental Differences Disappear in Speech plus Gesture

Finally, when we investigated the descriptions in speech and in speech plus gesture, we found that the developmental differences between adults and children disappeared for the viewpoint dependent sagittal spatial relations. When children's speech is combined with gestures, they reached adult levels in terms of the frequency of informative spatial expression. On the other hand, children's speech plus gesture spatial expression did not change the topological spatial relation's frequency of informative spatial expression because children and adults were already equally frequently informative for topological relations based on what they expressed in speech only. Thus, they were still equally frequently informative in speech plus gesture. These findings highlight an interaction between visually motivated expressions of space and the complexity of the spatial relations.

Importantly, gestures do not always make the developmental differences disappear between adults and children. For instance, in viewpoint dependent lateral spatial relations (Karadöller et al., 2021, under review), children could not reach the adult levels in the frequency of informative descriptions even when their speech was combined with gestures. It can be because of the fact that the lateral spatial relations are harder than sagittal spatial relations. Thus, if children have not reached a certain development in speech, their speech plus gestures may not reach the frequency of informative spatial expression in the adult level. Our data and previous literature showed a variation across different complexity of spatial relations in the speech plus gesture frequency of informative spatial relation expressions. Children's speech plus gesture frequency of informative spatial expressions can reach the adult level only in moderately challenging viewpoint dependent sagittal spatial relations. This suggests that there are limits in multimodal expressions of spatial relations. On one hand, sometimes gestures can be redundant with speech. On the other hand, there are also instances where gestures cannot be enough for the expression even when they accompany the speech.

5. 5. Implications of the Study

The current study has an implication for the children's daily life. Children's gestures may convey information that they do not state in their speech. Thus, the education system should consider findings of our work and previous research. In the school settings, children can be encouraged to produce gestures, in that way, gestures can make the information more accessible to children. Also, teachers can consider gestures as an additional assessment criterion. Students may not express concepts in speech yet, but their gestures may give the information especially in the lessons like math that spatial relations are relevant. Gestures reveal early development and understanding; thus, school settings should evaluate it.

5. 6. Limitations and Future Directions

The current study revealed important findings that future studies can benefit from and but also has limitations that future research may need to consider. First of all, one important issue that needs to be considered is the features of our materials that might be investigated further. We had non-intrinsic front and behind objects as experimental materials. However, in the development of the sagittal axis intrinsic and non-intrinsic objects may have a variation. Children may express front and behind earlier for intrinsic front and behind side objects. Thus, in our study children have an additional challenging factor, so the feature of the front and behind might have been a limitation. Also, as discussed above, our materials may have also affected why we did not find asymmetry between front and behind spatial term expressions. Future research may investigate those issues by comparing the intrinsic and non-intrinsic featured objects.

Furthermore, as discussed above, our study cannot make a claim about which function of gesture is more dominant in spatial expressions. We did not measure the addressee's perspective and how much the addressee correctly identified the spatial relations by participants' descriptions. If we had measured this, then we could compare the gesture and no-gesture conditions from the addressee's perspective. Additionally, no addressee or more actively communicated addressee conditions may affect the gesture production. Future research may consider this issue by manipulating the characteristics of the addressee.

5. 7. Conclusion

The current study investigated children's and adults' multimodal spatial language expressions with two spatial relations that vary in complexity. Previous literature mostly agreed that gestures increase frequency of informative spatial descriptions (Sauter et al., 2012; Sekine, 2009). However, multimodal spatial expressions did not always increase the children's frequency of informative descriptions to the adult level (Karadöller et al., 2021, under review). The limits of the multimodal spatial expressions tested by the present study with the spatial relations that acquired earlier in the development. The results of the study showed that children use gestures as an additional informativeness tool for viewpoint dependent sagittal relations. In other words, if the spatial relations are more challenging, children benefit from visual modality more. Furthermore, when children's speech is combined with gestures, the total frequency of informative descriptions reaches the adults' frequency. These results showed that gestures reveal earlier development and with speech plus gestures children can be informative as much as adults. However, children and adults were equally frequently informative in their speech for topological spatial relations. Thus, the total speech plus gesture frequency of informative spatial expression did not add new information. This study demonstrated the limits of multimodal expressions with the spatial relations that are acquired earlier in the development. Yet, there are many limits of multimodal expressions that are open to investigation. Future research may test those limits with different spatial relations.

APPENDICES

APPENDIX A

List of abbreviations used in the present study.

Abbreviations

GEN	Genitive
POSS	Possessive
LOC	Locative

APPENDIX B

List of the experimental stimuli used in the present study.

EXPERIMENTAL STIMULI LIST

bag card in	mug creditcard behind
bag chain front	mug dishsponge2 on
bag charger on	mug drainer on
bag giftboxred behind	mug mirror front
bag headphones behind	mug mouse behind
bag parfumepink front	mug paintbrushwood in
bag pear in	mug scissorssmall behind
bag tissue in	mug spoon front
book boardmarker2 behind	pan cookingbrush front
book crayon behind	pan cookingspoonplastic on
book crown on	pan eggplant front
book duster on	pan peppergreen in
book garlic on	pan smallrollingpin front
book makeupbrush on	pan spatula1wooden behind
book pacifier front	pan strainer behind
book teabag behind	pan towel in
box alarmclock in	paper cap front
box calculator behind	paper coke on
box hairdryer front	paper hairband on
box magnifier in	paper kiwi behind
box mike in	paper onion behind
box pencilbox2red on	paper pen behind

box treebranchwithleaves in
box videocam front
cookingpot brush1blue front
cookingpot grater in
cookingpot ladle2metal behind
cookingpot latch2red behind
cookingpot pepperred in
cookingpot spatula2plastic on
cookingpot umbrella1red on
cookingpot whisker2plastic front
envelope battery on
envelope bracelet on
envelope clothespin front
envelope metalkey in
envelope nailbrush on
envelope nailclipper front
envelope pills in
envelope thermometer front
foodbox blueflag front
foodbox flower2 front
foodbox latch1blue behind
foodbox lid in
foodbox napkinwhite in
foodbox notebook1black in
foodbox paintbrush1plastic in
foodbox pencilbox1black behind
hat ipad behind
hat notebook2orange front
hat ruler2plastic in
hat shawl in
hat tie1 behind
hat tshirt on
hat umbrella2green behind
hat waterbottle on
paper rubber on
paper stamp on
plate brush2red in
plate cheese in
plate glassesbox in
plate greenflag behind
plate knife2 front
plate lemonjuicer in
plate napkin2red front
plate tie2 front
shoe balloongreen in
shoe boardmarker1 front
shoe bulb in
shoe cam on
shoe leaf front
shoe lighter in
shoe shoesponge on
shoe sock on
slipper cd behind
slipper creamtube front
slipper giftbox2metal behind
slipper glasses on
slipper injection in
slipper parfumeblack front
slipper phoneold behind
slipper purse behind
tray apple behind
tray ball on
tray bottleopener behind
tray candlesmall on
tray funnel on
tray salt front
tray smallbottle front
tray string on

APPENDIX C

List of the filler stimuli used in the present study.

FILLER STIMULI LIST	
basket flute left	jar screwdriver right
basket hammer right	jar soapbar right
basket knife1 right	jar whistle left
basket ladle1plastic right	jar wristwatch left
basket nailpolish left	moneybox balloonorange left
basket newspaper left	moneybox leaflong right
basket remote right	moneybox lock right
basket toiletpaper left	moneybox money right
bowl bread right	moneybox mpikey left
bowl cookingspoonmetal right	moneybox ribbon left
bowl cuttingboard left	moneybox stone right
bowl rulerwooden left	moneybox straw left
bowl tomato right	plantpot carrot right
bowl tongs right	plantpot dishsponge left
bowl treebranch left	plantpot handfan right
bowl whisker1metal left	plantpot iphone right
cup chocolate left	plantpot orange right
cup egg right	plantpot sunglasses left
cup fork right	plantpot torch left
cup lollipop left	plantpot wool left
cup pastry left	vase banana left
cup pencil left	vase candlelong right
cup tape right	vase comb right
cup toothbrush right	vase corn left
jar jarlid right	vase flower1 right
jar lemon right	vase glove right
jar mandarin left	vase scissorsbig left
jar razor left	vase wallet left

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