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Spatial orientation assessment in preschool children: Egocentric and allocentric frameworks

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ABSTRACT

Spatial orientation is an important function in daily life because it allows us to reach a target place when moving through our environment, using self-centered (egocentric) or environmental information (allocentric). Compared to other cognitive functions, spatial orientation has been studied less in preschool ages. Some brain areas, such as the hippocampus and the temporal as well as the parietal and frontal cortices, are involved in spatial orientation. Therefore, when these brain regions are altered in neurological conditions or in atypical development in children, we would expect impairment of spatial abilities. The aim of this study is to review studies, published in recent years, that use egocentric and allocentric spatial orientation tasks for assessing spatial memory in preschool children, with the final goal of finding out which tests could be included in a clinical neuropsychological evaluation. We observed that although egocentric spatial orientation emerges first during development, allocentric spatial orientation tasks are employed at very early ages. Most of these tasks are performed in real environments, allowing children's self-movements and using environmental modifications, but technologies such as virtual or augmented reality are increasingly used. Other aspects are discussed, such as the lack of consensus in the nomenclature, the difficulty of tracing the course of development of spatial orientation, or the ecological validity of the tests used. We finally observed that there is greater interest in studying the allocentric framework than the egocentric one, which makes it difficult to compare the use of the two frames of reference during a neuropsychological evaluation in preschool-aged children.

KEYWORDS
Frames of reference; preschoolers; spatial memory; spatial orientation; topographical disorientation; young children

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Introduction

In our daily lives, we need to employ several cognitive functions that work with visual and spatial information, ranging from simple tasks, such as remembering in which drawer of the room we put an object, to complex tasks, such as remembering the path we need to follow to reach a distant place. The former example describes memory for locations, related to object recognition, recall of positions of objects, or knowing when an object has been moved from its original position (Bocchi et al., 2018). The latter example refers to spatial orientation or spatial navigation, which is the aim of the present review. Spatial orientation allows us to find a target place by moving through the environment to reach the target location. To do this, it is necessary to remember the location, use information about the direction, angle, or distance, and specify the location with regard to two cues: a stable and unchanging reference point and/or a subject who moves (Vasilyeva & Lourenco, 2012; Waismeyer & Jacobs, 2013). Thus, spatial orientation not only requires coding such information or key points in the environment, but also knowing how to use them to relocate to a previously known or visited place. Hence, all of this information allows us to eventually reach our target location, identifying our surrounding environment and our location and reorienting in previously known places. Therefore, we can see that spatial orientation involves location memory, and this function is more complex than visual orientation.

Egocentric vs allocentric spatial orientation

For spatial navigation, we mainly employ two frameworks: egocentric and allocentric. The egocentric system involves taking our own body as the reference

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center, so that all locations are related to our own point of view, whereas the allocentric system employs elements in the environment regardless of our own position (Burgess, 2008; O'Keefe, Nadel, & Lynn, 1978; Vasilyeva & Lourenco, 2012). A third frame of reference has been pointed out, the heterocentric framework, which takes the perspective of a third person (Ruby & Decety, 2001). However, this framework has not been considered in the present review. The egocentric framework is related to a concept known as dead reckoning, or path integration, the ability to update and track our own movements by codifying our speed or acceleration, as well as distances, turns, and directions, called idiothetic signals (Montello, 2005). This capacity requires awareness of our initial location, and it involves vestibular, kinesthetic, and optic systems (Newcombe, Huttenlocher, Drummey, & Wiley, 1998; van den Brink & Janzen, 2013). The allocentric framework is related to the ability to recall and recognize landmarks—allothetic signals—to finally be able to make mental maps as representations of the surrounding environment (Burgess, Maguire, & O'Keefe, 2002; Montello, 2005; O'Keefe et al., 1978). These external allothetic cues can be coincident or not coincident: coincident cues code the location's properties or the reference landmarks that coincide with the target place, whereas noncoincident cues refer to relative positions that require the ability to employ distances and directions related to the target place (Waismeyer & Jacobs, 2013). Moreover, when we talk about a noncoincident landmark, we can refer to environmental landmarks inside the task enclosure or near a target location, called proximal cues or intramaze landmarks, or we can refer to external environmental cues not located in the enclosure or far from the target location, called distal cues or boundary landmarks. Therefore, if we hide a toy under a box decorated with a distinctive pattern, children could memorize the position of the box on the floor of the room and its distinctive feature (a coincident cue), but they could also code that the target box is next to the teddy bear (a proximal noncoincident cue) or just below the window (a distal noncoincident cue).

For completely functional spatial navigation, it is not enough to have these environmental cues and our own organism's cues, statically or in locomotion. Instead, it is necessary to integrate and combine them to eventually recreate integral images of spatial representations (Nardini, Jones, Bedford, & Braddick, 2008). Thus, taking into account that the egocentric framework is the first to emerge in development (Acredolo, 1978; Acredolo & Evans, 1980; Piaget & Inhelder, 1967), and based on the model of environmental knowledge acquisition (Siegel & White, 1975), the development of the allocentric framework and its association with the egocentric framework takes place in the following way. First, in landmark knowledge acquisition, we can recognize landmarks in the environment, but not to employ directional information about them, such as their location and their association with other stimuli and the environment. Second, in route knowledge, we can employ egocentric information in combination with consecutive landmarks, allowing us to follow a route. Third, in survey knowledge, we can memorize landmarks in an organized mental map. Therefore, the allocentric response starts with remembering landmarks, then combining them with egocentric information, and concluding with the creation of mental maps, indicating that allocentric orientation is fully developed, which occurs at about the age of seven (Overman, Pate, Moore, & Peuster, 1996). Therefore, it seems relevant to assess spatial orientation development before the age of seven.

Typical tasks to measure egocentric and allocentric spatial orientation

Prototypical tasks used for the evaluation of the egocentric and allocentric frames of reference take place in rooms specifically equipped for the test. In the case of the egocentric framework, the room or enclosure has not environmental cues in order to force the use of turns and body movements to guide behavior. In the case of the allocentric framework, visual cues would be added. The final aim of allocentric tasks is usually for the child to find a stimulus or toy in a hidden place within the room, guided either by his own turns and/or body movements in the egocentric framework, or by the cues located in the environment in the allocentric framework.

Development of spatial orientation related functions

Regarding brain development during childhood and spatial orientation improvements, other early sensorial and cognitive functions have to develop first. That is, to correctly perceive the environment, discriminate landmarks, locate objects spatially, etc., children need to move their eyes and head across their visual field in order to explore it. On eye-tracking tasks, infants are encouraged to follow a stimulus across their visual field. This requires infants to able to voluntarily control their eye movements. Newborns are only able to

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perform eye tracking tasks, fixing their attention on a specific stimulus, although this ability improves significantly at 3 months (Clohessy, Posner, & Rothbart, 2001) and continues to improve until 6 months (Reynolds & Romano, 2016). Therefore, between 3 and 6 months of age, infants begin to have the ability to voluntarily control their eye movements, which is related to exploring their visual field. At 6 months, infants are able to maintain their attentional focus for longer periods of time (Reynolds & Romano, 2016), and at the age of one year, they start to inhibit nonrelevant stimulation (Garon, Bryson, & Smith, 2008). From this age onward, infants can sustain their attentional focus longer and tolerate more interfering information (Garon et al., 2008). At 6 months old, infants also start to detect and anticipate changes in the positions of objects previously shown, as a very first sign of visuospatial memory (Gilmore & Johnson, 1995; Oakes, Hurley, Ross-Sheehy, & Luck, 2011; Reznick, Morrow, Goldman, & Snyder, 2004). This function continues improving significantly between 6 and 8 months (Pelphrey et al., 2004), but infants still have a high rate of mistakes when trying to locate an object between two possible positions until 9 months old (Diamond & Goldman-Rakic, 1989). From 9 months to one year, searching errors almost disappear (Diamond & Goldman-Rakic, 1989). In addition, infants start to be able to tolerate a longer delay period, a period of time where the child is not allowed to initiate searching behavior, from 2 seconds at 6 months to 10 seconds at 12 months (Diamond & Goldman-Rakic, 1989; Pelphrey et al., 2004; Reznick et al., 2004).

Some brain areas participate in the development of spatial orientation. Hippocampal maturity has been associated with allocentric memory enhancement, due to projections from the entorhinal cortex to the CA1 area (Lambert, Lavenex, & Banta Lavenex, 2015), which occur at 2 years of age, approximately.

Spatial orientation and brain structure and function

In adult humans, on the one hand, the allocentric orientation has mainly been related to the hippocampus, parahippocampus, retrospenial, and inferior and superior temporal cortex, but also to the frontal, parietal, and occipital cortex (Boccia, Nemmi, & Guariglia, 2014; Chen et al., 2014; Committeri et al., 2004; Doeller, King, & Burgess, 2008; Nemmi, Boccia, & Guariglia, 2017; Saj et al., 2014; Zaehle et al., 2007). On the other hand, the egocentric orientation is associated with the precuneus, inferior, and superior parietal cortex, superior temporal cortex, and frontal cortex, as well as some subcortical structures, such as the striatum, thalamus, and insula (Chen et al., 2014; Doeller et al., 2008; Moulinet et al., 2016; Neggers, Van der Lubbe, Ramsey, & Postma, 2006; Nemmi et al., 2017; Zaehle et al., 2007). However, most of these areas are shared by both frameworks, especially the precuneus, parietal, temporal, and medial and superior frontal cortex (Chen et al., 2014; Neggers et al., 2006; Saj et al., 2014; Zaehle et al., 2007). Both strategies seem to involve a parieto-frontal bilateral network that mainly includes parietal and premotor regions, but can also include visual occipital regions (Gramann et al., 2010; Zaehle et al., 2007).

Spatial orientation in pediatric neurological populations

This aforementioned course of development of spatial abilities occurs in children with regular brain development. However, other cognitive abilities with a spatial component, such as visuospatial memory or visuospatial abilities, have been investigated more in children with early brain damage, atypical development, or other neurological conditions. For example, some difficulties have been found in these functions in premature children, compared to term-born children in (Beauchamp et al., 2008; Caravale, Tozzi, Albino, & Vicari, 2005; Mürner-Lavanchy et al., 2014), due to a reduction in hippocampal volume (Aanes, Bjuland, Skranes, & Løhaugen, 2015; Beauchamp et al., 2008). As mentioned previously, spatial orientation is a complex function based on the correct functioning of other sensory and cognitive systems, which leads us to imagine that space navigation may be affected in preterm children. For example, spatial orientation deficits have been observed in preterm, school-aged populations (Cimadevilla, Roldán, París, Arnedo, & Roldán, 2014). In other clinical populations, such as Williams syndrome (Bernardino, Mouga, Castelo-Branco, & Van Asselen, 2013; Broadbent, Farran, & Tolmie, 2014; Nunes et al., 2013; Vicari, Bellucci, & Carlesimo, 2003), Down syndrome (Lavenex et al., 2015), cerebral palsy (Belmonti, Fiori, Guzzetta, Cioni, & Berthoz, 2015), and fetal alcohol syndrome (Hamilton, Kodituwakku, Sutherland, & Savage, 2003), spatial orientation and visuospatial difficulties have been found as well. It is noteworthy that there is a disorder directly related to difficulties in spatial orientation development, that is, developmental topographical disorientation (DTD). Many cases of

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children and adults with this pathology have already been recorded (Bianchini et al., 2014; Conson et al., 2018; Iaria & Barton, 2010; Iaria, Bogod, Fox, & Barton, 2009; Iaria et al., 2005; Nemmi et al., 2015; Palermo, Foti, Ferlazzo, Guariglia, & Petrosini, 2014; Palermo, Piccardi, et al., 2014), although we find that it has not yet been studied in depth compared to other neurodevelopmental disorders, and most of this population is detected in adulthood, pointing to a difficulty in detecting these problems in childhood at the present time. This pathology is characterized by problems related to topographic knowledge and environmental navigation, which may include difficulties such as recognizing landmarks, being aware of the position of the head, recognizing right-left directions, adapting to changes or alterations in previously learned routes, and, mainly, creating and later using cognitive maps (Iaria & Barton, 2010). All these difficulties have been reported without presenting any type of cerebral lesion and with other neuropsychological functions intact.

Not only in clinical populations, but also in children with typical development, we find that spatial capacities play a vital role, due to their influence on academic achievement (Bull, Espy, & Wiebe, 2008; Demir, Prado, & Booth, 2014). Therefore, all these disorders or difficulties show the importance of using spatial orientation tests for preschool ages that allow us to detect early problems in this ability that could influence later cognitive development, academic aims, or even quality of life.

Present review

In spite of the vital importance of this capacity in our daily activities and in some neurological-related disorders, we find that, compared to other cognitive functions, not much attention has been paid to egocentric and allocentric evaluations during childhood. For all these reasons, it seems necessary to employ tests for these spatial orientation frames of reference from the earliest ages and throughout childhood, according to their brain development. Therefore, the aim of the present review is to identify and summarize the current state of knowledge on the egocentric and allocentric spatial orientation assessment tests for populations up to 6 years old that have been published in recent years. This review also aims to examine the methodological differences in spatial orientation assessment. Some tasks allow children to move, as we currently know that self-movement is relevant for orientation, while others do not allow movement or displacement. Similarly, some of the tasks use natural environments with some modifications, while others use technologies, such as computerized tasks, augmented reality or virtual reality. This review also sought to include a summary of the course of spatial orientation development, in order to clarify how this function improves in children with typical development. The knowledge about typical development could help to detect when there are dysfunctions, allowing clinical neuropsychologists to compare normal development with potential problems in spatial egocentric and allocentric function. Finally, this review also includes a critical discussion of the current panorama on the evaluation of spatial orientation in children, as well as limitations and directions for future research.

Method

A systematic literature review was conducted by searching in three psychological databases (Pubmed, PsycINFO, and Scholar Google) in order to identify peer-reviewed articles that employed spatial orientation tasks in children (age: 0–6 years). The studies included were published between 2000 and 2019. A description of the selection method is included in the supplementary material (see Figure 1).

Results

Sample description and study characteristics for the 49 studies are located in Table 1.

Egocentric versus allocentric spatial orientation assessment

Eighteen studies from 49 articles examined assessed egocentric spatial orientation using spatial tasks, out of (Bremner, Hatton, Foster, & Mason, 2011; Bullens, Iglói, Berthoz, Postma, & Rondi-Reig, 2010; Crowther, Lew, & Whitaker, 2000; Gouteux, Vauclair, & Thinus-Blanc, 2001; Juan, Mendez-Lopez, Perez-Hernandez, & Albiol-Perez, 2014; Kaufman & Needham, 2011; Leplow et al., 2003; Lew, Bremner, & Lefkovitch, 2000; Lew, Foster, & Bremner, 2006; Nardini, Burgess, Breckenridge, & Atkinson, 2006; Nardini, Jones, et al., 2008; Piccardi et al., 2014; Piccardi, Leonzi, D'Amico, Marano, & Guariglia, 2014; Piccardi, Palermo, Bocchi, & Guariglia, 2015; Ruggiero, D'Errico, & Iachini, 2016; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013; Yang, Merrill, & Wang, 2019). In 7 of these articles the emission of a self-centered response is

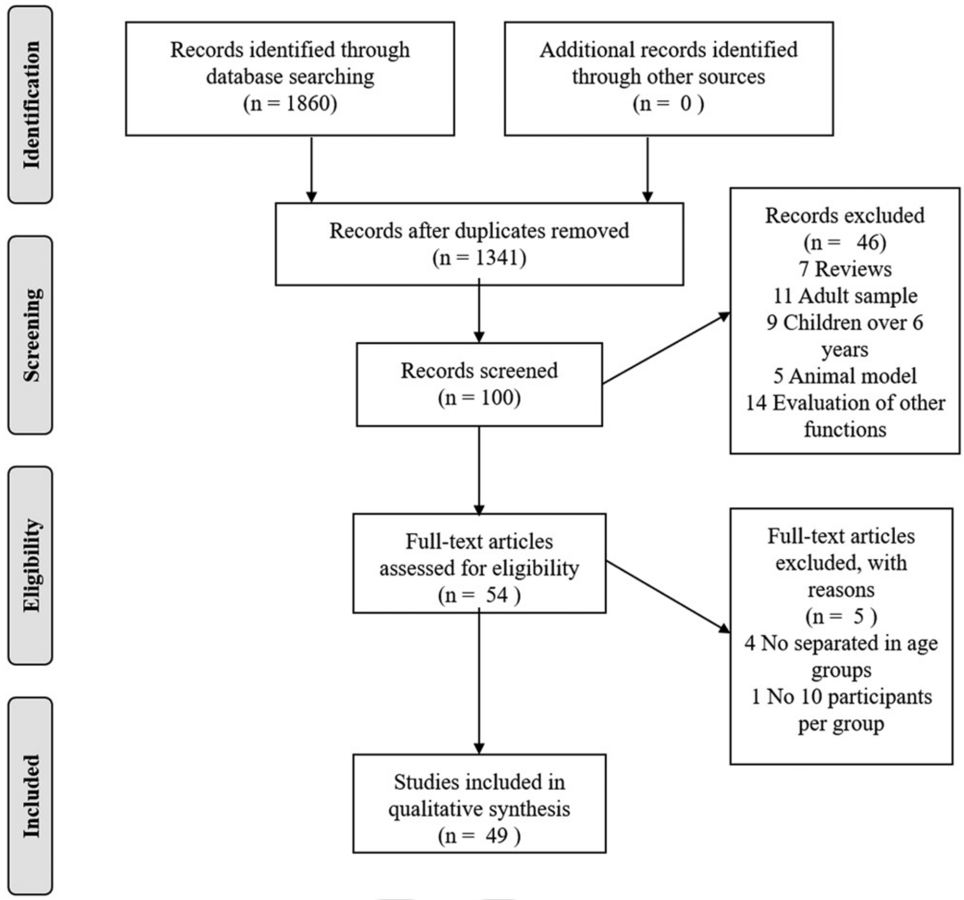

Figure 1. Flow of full-text articles selected for revision according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

considered erroneous or noneffective (Gouteux et al., 2001; Kaufman & Needham, 2011; Leplow et al., 2003; Lew et al., 2006; Nardini, Jones, et al., 2008; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013), because the main aim of these tasks is to know whether the children are capable of using external environmental landmarks. The only studies that used tasks that can only be solved using egocentric cues did not aim to analyze, as the main objective, the performance on this framework, but rather to measure the visuospatial span (Juan et al., 2014; Piccardi, Leonzi, et al., 2014; Piccardi, Palermo, et al., 2014), locating one or more objects among several possible locations, as well as walking according to a specific pattern through squares placed on the floor. The studies also assessed what type of egocentric information is used more effectively (Bremner et al., 2011) when visual flow or vestibular information, or egocentric information is available along with allocentric clues, hindering the use of egocentric strategy by itself (Yang et al., 2019).

Forty studies from 49 articles examined evaluated the allocentric spatial orientation. In 32 of these articles noncoincident landmarks were used (Bullens, Iglói, et al., 2010; Bullens, Nardini et al., 2010; Bullens, Klugkist, & Postma, 2011; Crowther et al., 2000; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001; Learmonth, Newcombe, Sheridan, & Jones, 2008; Lee, Sovrano, & Spelke, 2012; Lee & Spelke, 2010, 2011; Lee, Winkler-Rhoades, & Spelke, 2012; León, Cimadevilla, & Tascón, 2014; Lew et al., 2000, 2006; Lourenco, Addy, & Huttenlocher, 2009; Lourenco & Cabrera, 2015; Mandolesi, Petrosini, Menghini, Addona, & Vicari, 2009; Merrill et al., 2016; Nardini, Atkinson, & Burgess, 2008; Nardini et al., 2006; Nardini, Jones, et al., 2008; Negen, Heywood-Everett, Roome, & Nardini, 2018; Newcombe, Ratliff, Shallcross, & Twyman, 2010; Pentland, Anderson, Dye, & Wood, 2003; Piccardi et al., 2015; Rodriguez-Andres, Juan, Mendez-Lopez, Perez-Hernandez, & Lluch, 2016; Rodriguez-Andres, Mendez-Lopez, Juan, & Perez-Hernandez, 2018; Ruggiero et al., 2016; Yang et al., 2019; Yousif & Lourenco, 2017), while one article used coincident landmarks (Kaufman & Needham, 2011). The combination of the two type of

Q4 **Table 1.** Characteristics of reviewed studies about spatial orientation assessment under 6 years.

Reference Author, Year	Age + N[a]	Egocentric strategy[b]	Allocentric strategy[c] Coincident / Noncoincident	Allocentric strategy[c] Distal/ Proximal	Electronic equipment / Environmental modifications[d]	Self-movement allowed[e]	Brief results[f]
Bremner et al., 2011	6 to 14 months (252)	Yes	–	–	EM	No	Infants at 7 and 12 months use information based on visual flow to reorient themselves; whereas, at 9 months, they use vestibular information more effectively. At all ages, however, they appear to be sensitive to both types of information, but they do not integrate them efficiently.
Bullens, Nardini, et al., 2010	5, 7, and 10 (57)	Yes	NC	D	EE	No	Although 5-year-olds obtain spatial learning scores similar to those of older ages, they perform the task more slowly than the 10-year-olds. In addition, at age 5, there is a clear preference for adopting an egocentric orientation strategy, which persists at higher ages but in a less marked way. Although the 5-year-old group does not spontaneously use the allocentric strategy, they perform above chance when the use of this orientation response is imposed.
Bullens, Nardini, et al., 2010	5 and 7 + Adult group (45)	–	NC	P + D	EM	Yes	From 5 years of age, children are able to use distal and proximal allocentric landmarks to solve the task. The performance does not differ significantly depending on the type of cue used.
Bullens, Klugkist, and Postma, 2011	5, 7, and 9 (46)	–	NC	P + D	EM	Yes	Five-year-old children perform less accurately than their older peers. Children at this age improve their performance by employing visual information for orientation and benefitting from local landmarks, compared to older children. At all ages, scores are better when the point of view is the same between sample and trials.
Crowther et al., 2000	6 and 8.5 months (64)	Yes	NC	P	EM	No	The presence of an allocentric cue does not guide reorientation at 6 months. At 8.5 months, performance improves if a distinctive allocentric cue is present, compared to a purely egocentric condition, although in spite of this, they do not reach scores above chance.
Gouteux and Spelke, 2001	3 to 4.5 (37)		C + NC	P	EM	Yes	Between 3 and 4.5 years of age, children are not able to reorient following the geometric properties of the environment or establish geometric relationships between the available objects, unless these relationships are explicitly shown (for example, with physical elements that link the different objects). Certain nongeometric characteristics, such as shape and color, do guide their reorientation, but only when they are coincident landmarks.
Gouteux, Vauclair, and Thinus-Blanc, 2001	3, 4, and 5 + Adults group (80)	Yes	C + NC	P + D	–	No	At 4 and 5 years of age, children begin to be able to use geometric proximal cues, whereas children at 3 years old emit random responses, which could be related to an egocentric strategy. At 4 years of age, they begin to use nongeometric cues, such as color, integrated with distal environmental landmarks, perfecting their execution at 5.
Hermer-Vazquez et al., 2001	3 to 6.5 (56)	–	C + NC	P	EM	Yes	Children at 3 years of age begin to be able to use nongeometric cues such as color, only when they are coincident, whereas around 5 years old, they are used as coincident and noncoincident. The ability to use these cues is related to the linguistic production capacities for verbal material (such as "it is to the right of"), but not as much to the comprehensive skills.
Hupbach and Nadel, 2005 Experiment 1	4 to 6 (46)	–	NC	P + D	–	No	Children at age 4 are not able to use the geometric information provided by the rhombic device used for the task, but they employ distal environmental cues more effectively. At 5 and 6 years old, they are able to use both types of information, geometric and nongeometric.
Hupbach and Nadel, 2005 Experiment 2	2 to 6 (63)	–	NC	P	EM	Yes	At 2 and 3 years of age, children cannot use proximal cues to reorient provided by the geometry of the apparatus used in the task, although they achieve it between 4 and 6 years of age. When they are given a distinctive environmental landmark, responses at 2 and 3 years old are still random, whereas older children can use both the geometric information from the device and the nongeometric information provided by the environmental

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							cue, without either of the two information types predominating in their behavior.
Huttenlocher and Vasilyeva, 2003	20 to 24 months (98)	–	NC	P	EM	Yes	Toddlers between 20 and 24 months can be reoriented using geometric cues, both when they are inside a closed room, in this case triangular, and when they are outside the space and perform the task on a small scale. The strategy followed by most children is to go directly to the correct location, which seems to be related to the coding of space in terms of the internal relationships between its parts.
Juan, Mendez-Lopez et al., 2014	5 to 8 (76)	Yes	–	–	EM + EE	Yes	At 5 and 6 years old, children are able to locate 1 object between 2 locations and/or 2 objects among 4 locations in an enclosure without environmental cues and using augmented reality technology.
Kaufman and Needham, 2011	4 to 5 months (88)	Yes	C	P	EM	No	Infants at 4.5 months are able to show a pattern of nonegocentric orientation. However, these results only occur when the child has been previously moved in the environment, with the opportunity to explore it from different locations. The familiarization with the place of the test, even in the absence of autonomous locomotion, seems to favor the use of an allocentric point of view at such an early age.
Learmonth et al., 2002	3, 4, 5, and 6 (69)	–	NC	P	EM	Yes	At 3 and 4 years old, children are able to use the geometric cues of the environment to reorient themselves in a rectangular enclosure, but when this enclosure has a small size, they are not able to use distinctive environmental cues. At age 5, reorientation only occurs if the enclosure has a larger size, with no problems in relocating to any size of enclosure at 6 years of age.
Learmonth et al., 2001	17 to 24 months (247)	–	C + NC	P	EM	Yes	Infants between 17 to 24 months are able to use different allocentric cues to reorient themselves, on the one hand, both a single key and two distinctive environmental keys, and on the other hand, another type of geometrical or visual cue, such as color, the length of surfaces, and the relationship they maintain with each other.
Learmonth et al., 2008	3, 4, 5, and 6 (221)	–	NC	P + D	EM	Yes*	At 3 and 5 years old, when children need to reorient themselves in a small space while having limited mobility, they are not able to use environmental cues (colors, geometry) to do this correctly, although they can do so at 6 years old. When their movements are limited but the search area is more distal, children begin to correctly use the previous cues from 4 years of age, observing that the proximity of the target place to environmental cues influences the use of such information to reorient. If 3-year-old children are given a previous experience of free movement, they are also able to reorient themselves using these environmental cues. Free locomotion and exploration of the environment is important for the use of allocentric cues at 3 years of age, whereas at older ages, these functions lose importance until 6 years of age.
Lee, Sovrano, and Spelke, 2012	2 to 3 (112)	–	NC	P	EM	Yes	At 2 and 3 years of age, children are able to use geometric cues not explicitly indicated, such as distance and directional relationships between surfaces, to reorient in a rhombic or rectangle-shaped enclosure. If these enclosures are presented in a fragmented way—separate walls—instead of continuously, children's reorientation responses are random.
Lee and Spelke, 2010	3 to 3.9 (112)	–	NC	P	EM	Yes	At 3 years of age, children are able to use 3D objects as cues in a circular environment, as well as being able to perform the task if these objects are moved. Children are unable to reorient themselves when the noticeable cues are in two dimensions or when the relationship between the object and the surrounding environment cannot be established.
Lee and Spelke, 2011	3 to 4 (64)	–	NC	P	EM	Yes	Orientation of children between 3 and 4 years old using geometric cues is better when these are 3D representations, with the influence of small changes in the structure, but not in the distances, directions, brightness, shadows, or salience of the objects.

(*Continued*)

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Table 1. Continued.

Reference Author, Year	Age + N[a]	Egocentric strategy[b]	Allocentric strategy[c] Coincident / Noncoincident	Allocentric strategy[c] Distal/ Proximal	Electronic equipment / Environmental modifications[d]	Self-movement allowed[e]	Brief results[f]
Lee, Winkler-Rhoades, et al., 2012	1.5 to 3.5 (96)	–	NC	P	EM	Yes	Children at 2 years of age are able to use geometric patterns located on the walls of the enclosure to reorient when they have a particular size and density, although they cannot use cues related to clarity—darkness. At 3.5 years old, they efficiently use cues related to surface distances and shadows to orient themselves.
León et al., 2014	4 to 10 (100)	–	NC	D	EE	No	Children at 4 and 5 years old show poorer performance on a virtual task using distal allocentric cues than older peers. Children at 5 years old are able to improve their results throughout the different trials of the test, and they are able to solve the task when it remains at low levels of difficulty.
Leplow et al., 2003	3, 4, 5, 7, 10, and 12 + Adult group (112)	Yes	NC	P + D	EM	Yes	At 3, 4, and 5 years old, children are able to avoid giving a purely egocentric response, erroneous on this task, and use proximal allocentric cues for their reorientation. In contrast, when the proximal cues are changed and conflict with prior learning, the children are not able to support their responses on allocentric distal cues until 7 years of age.
Lew et al., 2000	6, 8.5, and 12 months (112)	Yes	NC	P	EM	No	An improvement in performance is observed in reorientation after 8.5 months, reaching correct response rates above chance at 12 months. Although at 12 months, infants are able to use a purely egocentric response, they get better performance when they have two allocentric cues available. With less effectiveness, also at 8.5 months, infants are able to use two allocentric cues for reorientation, obtaining better performance than if only one key is present (which requires the participation of an allocentric and egocentric strategy) or none (purely egocentric strategy).
Lew et al., 2006	12 to 18 months (72)	Yes	NC	P	EM	No	At 12 and 18 months, if the external cues are very noticeable and distinctive and the child has not been disoriented, infants are able to give an allocentric response. However, the performance is lower if, on the one hand, the child has been previously disoriented or, on the other, if the cues are identical—not distinctive—which involves an egocentric strategy.
Lourenco, Addy, and Huttenlocher, 2009	18 to 24 months (93)	–	NC	P	EM	Yes	Infants from 18 to 24 months are able to use linear scalar information, such as luminosity, to reorient, even if it occurs in isolation, although the performance they achieve is greater if several scalar dimensions are combined than if only one is present.
Lourenco and Cabrera, 2015	3 and 4 (192)	–	NC	P	EM	Yes	At 3 and 4 years old, children who are first exposed to distinctive environmental characteristics, such as color in a rhombic-shaped environment, are able to reorient themselves better in another enclosure where only geometric cues are available, in comparison with those children who do not have access to these previous distinctive cues. The performance at 4 years old was better than the performance at 3.
Mandolesi et al., 2009	3 to 8 (80)	–	NC	D	EM	Yes	Performance, as a lower commission of errors and time spent, improves with age. At younger ages (4 to 5 years old, approximately), girls show similar performance to older boys (5 to 5.5 years old, approximately).
Merrill et al., 2016	6 to 12 (145)	–	NC	D	EE	Yes	6 to 7 age group performed worse than their older peers. Gender differences were not significant at this age. Gender variable (boys), verbal memory and other spatial abilities, but not age, provide a significant portion of the variance in wayfinding performance.
Nardini, Atkinson, and Burgess, 2008	18 to 24 months (68)	–	NC	P	EM	Yes	At 18 and 24 months of age, infants are able to reorient themselves allocentrically following cues such as color or asymmetrically placed drawings, related to an orientation guided by the sense of "left-right" orientation.

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Nardini, Burgess, Breckenridge, and Atkinson, 2006	3, 4, 5, and 6 (73)	Yes	NC	P + D	–	Yes	After 3 years of age, children are able to employ both egocentric and allocentric strategies using noncoincident distal cues. After 5 years of age, they begin to use proximal noncoincident cues, including geometric cues, employing an *intrinsic frame of reference*.
Nardini, Jones, et al., 2008	4 to 5 and 7 to 8 (43)	Yes	NC	P	EM	Yes	At 4 and 5 years old, children show worse performance than older children. At this age, they perform better when only allocentric cues are available, compared to when there are only egocentric cues or when both are available.
Negen et al., 2018	3.5 to 4.5 (21)	–	NC	D	EE	Yes	On those trials where virtual locomotion is not allowed, children from 3.5 to 4 years old do not perform the task correctly. After 4 years of age, this condition is surpassed, leading to the conclusion that a strictly allocentric point of view is achieved at that age.
Newcombe et al., 2010	2, 3, 4, and 5 (86)	–	NC	P	EM	Yes	At 2 and 3 years of age, children are able to use regular and complex geometric environments for reorientation—octagonal environment. This information can also be used after 3 years of age, but they also begin to be able to use nonassociative cues (color) and spatial relationships (*to the left, to the right*). At 4 years of age, they are able to establish geometric relationships between the elements of the environment, guided by a distinctive landmark, as long as this task is carried out in a large environment with regular characteristics.
Pentland et al., 2003	5 and 6 (60)	–	NC	D	–	Yes	At 5 and 6 years of age, using noncoincident environmental cues, the children correctly perform the task when they have to find 2 objects among 5 possible boxes, but not when there are 4 objects among 9 possible boxes.
Piccardi, Palermo, et al., 2014 Piccardi, Leonzi et al., 2014	6 to 11 (129) + 4 to 11 (268)	Yes	–	–	EM	Yes	Six-year-old children achieve lower scores than older peers. The topographical span in children under 6 years of age is around 2 items, although this increases successively at different ages, with no differences between genders.
Piccardi, Palermo, et al., 2015	6 to 11 (81)	Yes	NC	P	EM	Yes	Age is related to the ability to understand terminology related to spatiality, as well as to learning a route when landmarks are available and later recognizing these landmarks among possible distractors. Thus, the younger age group (6 years) performs worse than their older peers on these tasks. It is also pointed out that a better understanding of spatial grammar is related to a better ability to locate landmarks, stressing that language is a capacity to be taken into account in spatial orientation.
Ribordy et al., 2013 Ribordy Lambert et al., 2017	2 to 5 (82 + 40)	–	C + NC	D	EM	Yes	Between 2 and 5 years old, high performance with coincident cues is achieved. For noncoincident cues, the children are able to perform the task at 2 years old when they have to choose the right place among 4 possible locations, but at 3.5 years they are able to perform the task when they have to choose between 18 locations, increasing performance with 2 and 3 rewards at 5 years old.
Rodriguez-Andres et al., 2016, 2018	5 to 10 (160)	–	NC	P + D	EE	No / Yes**	Children of 5 and 6 years old, compared to their older peers, are not able to remember the position of 3 objects on a table within a virtual environment that only allowed the use of allocentric cues, both distal and proximal, and they also took a longer time to complete the task, compared to older groups.
Ruggiero et al., 2016	6 to 7 + Older children + Adults (283)	Yes	NC	P	–	No	Children from 6 to 7 years old obtain worse performance, as well as a higher latency, than the rest of the child and adult age groups, although their performance was comparable to the 70- to 89-year-old group. This indicates that the effectiveness of spatial judgments takes an inverted "U" shape throughout the life cycle, and it is more marked for allocentric judgments.

(*Continued*)

Table 1. Continued.

Reference Author, Year	Age + N[a]	Egocentric strategy[b]	Allocentric strategy[c] Coincident / Noncoincident	Allocentric strategy[c] Distal/ Proximal	Electronic equipment / Environmental modifications[d]	Self-movement allowed[e]	Brief results[f]
Schmuckler and Tsang-Tong, 2000	6 months (40)	–	C + NC	P + D	EE	No	Infants at 6 months of age are able to recognize allocentric distal and proximal cues, and in spite of still lacking locomotion, they perform better when a situation of "self-movement" is recreated, leading to the idea that the ability to move has a close relationship with the correct spatial orientation.
Smith et al., 2008	3, 5, and 7 (36)	–	C + NC	P + D	–	Yes	Proximal and coincident cues facilitate orientation at all ages, as well as when the task is performed in large spaces, although the higher the age of the children, the greater the performance on reorientation in small spaces. Distal environmental cues begin to be used at 3 years old, but they are less used when the target locations are close to the child. At age 6, they use distal landmarks in any type of environment size, related to the capacity of integration of both types of allocentric information, both distal and proximal.
Twyman et al., 2007	4 and 5 (52)	–	C + NC	P	EM	Yes	Children at 4 and 5 years of age who are previously trained (learning an environmental cue—color—in an environment without any possibility of encoding geometric cues) are able to transfer the spatial information to other different environments to orient themselves. They are capable of using visual cues, such as color or the arrangement of elements in the room, for reorientation, despite the absence of previous training.
van den Brink and Janzen, 2013	2.5 to 3 (45)	–	C + NC	P + D	EE	No	At 2.5 years, children achieve better performance if there are environmental cues present and if the condition is congruent (if the virtual rotation of the subject and the direction of the target are the same). At 3 years old, achievement is equally correct in all experimental conditions.
Vasilyeva and Bowers, 2006	3, 4, 5, and 6 (270)	Yes	C + NC	P + D	–	Yes	Children from 3 years of age are able to use geometric information to reorient and transfer it to a 2D map, even when the information is not aligned and in the same position (but rotated 90 or 180), avoiding a purely egocentric response. When the information provided does not have a continuous pattern, but the children themselves have to establish the geometric relationship configuration (e.g., presenting them with a complete triangle vs. presenting them with 3 sticks corresponding to the vertex), the performance at 3 years old is poor, but it increases in each age group.
Waismeyer and Jacobs, 2013	3 to 4 (74)	Yes	C + NC	P + D	–	No/Yes**	Despite having been rotated, children were able to omit egocentric information and emit an allocentric response. When coincident cues are available, children aged 3 and 4 use these cues more than noncoincident cues. If there are no coincident cues, they prefer to use object-relative positions versus using distinctive proximal landmarks. Children at age 4 are able to locate the correct location in the presence of a single cue, but they are not able to do so at 3 years old.
Yang et al., 2019	6 to 11 + Adults (81)	Yes	NC	D	EE	Yes	Children from 6 to 8 years old are able to find the rewarded place in a radial labyrinth when 3 sources of information (egocentric, allocentric and metric) are available, reporting preference for allocentric cues. They are also able to solve the task when only allocentric cues are available, but fail when the only available information is metric. They perform worse in all conditions when compared to older children and adults.
Yousif and Lourenco, 2017	2.5 to 4.5 (84)	–	NC	P	EM	Yes	Between the ages of 2.5 and 5, children are able to use allocentric cue for their reorientation if the distances of the walls are placed, but also the length of the walls, when the amount of nonrelevant information is limited.

C: Coincident landmarks; NC: Noncoincident landmarks; D: Distal landmarks; P: Proximal landmarks; EE: Electronic equipment; EM: Environmental modifications.
*Self-movement is restricted, but allowed.
**Self-movement is allowed depending on the experiment carried out in the same paper and/or the experimental conditions.

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cues was found in 11 articles (Gouteux & Spelke, 2001; Gouteux et al., 2001; Hermer-Vazquez, Moffet, & Munkholm, 2001; Ribordy, Jabès, Banta Lavenex, & Lavenex, 2013; Ribordy Lambert, Lavenex, & Banta Lavenex, 2017; Schmuckler & Jewell, 2007; Smith et al., 2008; Twyman, Friedman, & Spetch, 2007; van den Brink & Janzen, 2013; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013).

Twenty-two studies used proximal cues (Crowther et al., 2000; Gouteux & Spelke, 2001; Hermer-Vazquez et al., 2001; Huttenlocher & Vasilyeva, 2003; Kaufman & Needham, 2011; Learmonth et al., 2002, 2001; Lee, Sovrano, et al., 2012; Lee & Spelke, 2010, 2011; Lee, Winkler-Rhoades, et al., 2012; Lew et al., 2000, 2006; Lourenco et al., 2009; Lourenco & Cabrera, 2015; Nardini, Atkinson, et al., 2008; Nardini, Jones, et al., 2008; Newcombe et al., 2010; Piccardi et al., 2015; Ruggiero et al., 2016; Twyman et al., 2007; Yousif & Lourenco, 2017), while those using both proximal and distal cues in the tasks were 14 (Bullens, Nardini, et al., 2010; Bullens et al., 2011; Gouteux et al., 2001; Hupbach & Nadel, 2005; Learmonth et al., 2008; Leplow et al., 2003; Nardini et al., 2006; Rodriguez-Andres et al., 2016, 2018; Schmuckler & Jewell, 2007; Smith et al., 2008; van den Brink & Janzen, 2013; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013) and those using only distal cues were 9 (Bullens, Iglói, et al., 2010; León et al., 2014; Mandolesi et al., 2009; Merrill et al., 2016; Negen et al., 2018; Pentland et al., 2003; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Yang et al., 2019).

The proximal cues usually used in the studies were traffic cones (Bullens, Nardini et al., 2010), small colored or geometrical wood pieces (Bullens, Klugkist, & Postma, 2011; Ruggiero et al., 2016), paper lanterns (Crowther et al., 2000; Lew et al., 2000), rhomboid tabletop (Hupbach & Nadel, 2005), cylindrical figures (Huttenlocher & Vasilyeva, 2003), colored paper squares (Learmonth et al., 2002), bookshelves and doors (Learmonth et al., 2001), columns (Lee, Winkler-Rhoades, et al., 2012), sculpture objects (Lew et al. 2006), led light figures (Nardini, Jones, et al., 2008), object pictures (Piccardi et al., 2015), toys (Waismeyer & Jacobs, 2013), colored or geometrically printed walls or curtains (Learmonth et al., 2008; Lourenco, Addy, & Huttenlocher, 2009; Lourenco & Cabrera, 2015; Nardini, Atkinson, & Burgess, 2008; Twyman et al., 2007), plastic boxes or colored glasses (Learmonth et al., 2001; Schmuckler & Jewell, 2007; Smith et al., 2008), as well as the use of the environment's own geometry as an allocentric cue (Gouteux et al., 2001; Lee, Sovrano, & Spelke, 2012: Yousif & Lourenco, 2017). The distal cues used were shaped neon lights (Bullens, Nardini et al., 2010), colored papers (Bullens et al., 2011), colored curtains and cardboards (Gouteux & Spelke, 2001; Hupbach & Nadel, 2005), and furniture (Gouteux et al., 2001; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Vasilyeva & Bowers, 2006). Studies assessing performance in outdoor tasks normally used distal cues, usually trees, swings, benches, water towers, and so forth (Mandolesi et al., 2009; Smith et al., 2008). Virtual tasks usually created natural environments using landmarks such as trees, mountains, rocks, or buildings, but pictures, doors, and windows were also used as landmarks when domestic environments were used (Bullens, Iglói, et al., 2010; León et al., 2014; Merrill et al., 2016; Negen et al., 2018; van den Brink & Janzen, 2013; Yang et al., 2019).

Studies using proximal and distal cues are based on the presence of both cues at the same time (Gouteux et al., 2001; Hupbach & Nadel, 2005; Rodriguez-Andres et al., 2016, 2018; Vasilyeva & Bowers, 2006). These studies used different experimental conditions in order to compare children's performance when an additional distinctive cue was used (Bullens et al, 2011; Learmonth et al., 2008; Smith et al., 2008; van den Brink & Janzen, 2013). The studies also assessed whether changing the position of one of the cues, while the others remain in the same place, has any effect on performance (Bullens, Nardini et al., 2010; Leplow et al., 2003; Nardini et al., 2006; Schmuckler & Jewell, 2007; Waismeyer & Jacobs, 2013). Thus, in these studies the experimental conditions were designed to create conflict between different types of landmarks, assess how an extra landmark can improve performance, or explore how children can use both proximal and distal landmarks at the same time.

Locomotion, equipment and technologies in spatial orientation

Thirty-eight of the 49 articles analyzed in the present review include all or some experimental conditions that require the child to move in order to solve the task (Bullens, Iglói, et al., 2010; Bullens, Nardini et al., 2010; Gouteux & Spelke, 2001; Hermer-Vazquez et al., 2001; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Juan et al., 2014; Learmonth et al., 2002, 2001, 2008; Lee, Sovrano, et al., 2012; Lee & Spelke, 2011, 2010; Lee, Winkler-Rhoades, et al., 2012; Leplow et al., 2003; Lourenco et al., 2009; Lourenco & Cabrera, 2015; Mandolesi et al., 2009; Merrill et al., 2016; Nardini, Atkinson, et al., 2008; Nardini et al.,

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2006; Nardini, Jones, et al., 2008; Negen et al., 2018; Newcombe et al., 2010; Pentland et al., 2003; Piccardi, Leonzi, et al., 2014; Piccardi, Palermo, et al., 2014; Piccardi et al., 2015; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Rodriguez-Andres et al., 2016, 2018; Smith et al., 2008; Twyman et al., 2007; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013; Yang et al., 2019; Yousif & Lourenco, 2017). Spatial orientation requires displacement around the navigational environment. For this reason, allowing children to move around during the tasks is a relevant issue. The tasks where the child does not move are mainly for the youngest children, aged 18 months or below (Crowther et al., 2000; Kaufman & Needham, 2011; Lew et al., 2000, 2006; Schmuckler & Tsang-Tong, 2000), where even if the infants do not move by themselves, they are usually moved by their caregivers. For older children, the tasks where self-movement is not allowed are those that use computers or other types of technologies (Bullens, Iglói, et al., 2010; León et al., 2014; van den Brink & Janzen, 2013), one task related to spatial judgments from a static position (Ruggiero et al., 2016), and one task carried out in a real environment as well (Gouteux et al., 2001). However, this does not occur in all the tasks that include technological equipment. For example, some studies use a virtual reality task in which the children are required to move (Negen et al., 2018), using active mobility interfaces during the virtual task, such as a platform for their feet and a car steering wheel (Rodriguez-Andres et al., 2016), and employing augmented reality in a real environment that allows them to use their own locomotion (Juan et al., 2014).

A total of 37 articles design spatial orientation tasks that happen in real environments (Bullens, Nardini et al., 2010; Bullens et al., 2011; Crowther et al., 2000; Gouteux & Spelke, 2001; Gouteux et al., 2001; Hermer-Vazquez et al., 2001; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Juan et al., 2014; Kaufman & Needham, 2011; Learmonth et al., 2001, 2008, 2002; Lee, Sovrano, et al., 2012; Lee & Spelke, 2010, 2011; Lee, Winkler-Rhoades, et al., 2012; Leplow et al., 2003; Lew et al., 2000, 2006; Lourenco et al., 2009; Lourenco & Cabrera, 2015; Mandolesi et al., 2009; Nardini, Atkinson, et al., 2008; Nardini, Jones, et al., 2008; Newcombe et al., 2010; Pentland et al., 2003; Piccardi, Leonzi, et al., 2014; Piccardi, Palermo, et al., 2014; Piccardi et al., 2015; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Ruggiero et al., 2016; Smith et al., 2008; Twyman et al., 2007; Vasilyeva & Bowers, 2006; Yousif & Lourenco, 2017). From these, 31 of them require some type of environmental modifications. These studies are mainly carried out in empty rooms or enclosures with different shapes (mainly square, rectangular or round enclosures, but also rhomboid, octagonal or radial labyrinths) and use curtains or panels to avoid access to distal cues (Bullens, Nardini et al., 2010; Bullens et al., 2011; Crowther et al., 2000; Gouteux & Spelke, 2001; Hermer-Vazquez et al., 2001; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Juan et al., 2014; Kaufman & Needham, 2011; Learmonth et al., 2008, 2002, 2001; Lee, Sovrano, et al., 2012; Lee & Spelke, 2010, 2011; Lee, Winkler-Rhoades, et al., 2012; Leplow et al., 2003; Lew et al., 2000, 2006; Lourenco et al., 2009; Lourenco & Cabrera, 2015; Nardini, Atkinson, et al., 2008; Nardini, Jones, et al., 2008; Newcombe et al., 2010; Piccardi, Leonzi, et al., 2014; Piccardi, Palermo, et al., 2014; Piccardi et al., 2015; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Twyman et al., 2007; Yousif & Lourenco, 2017). We also found some tasks that use the elements commonly present in the room (furniture, doors, windows, etc.) as allocentric landmarks for reorientation (Gouteux et al., 2001; Hupbach & Nadel, 2005; Nardini et al., 2006; Pentland et al., 2003; Vasilyeva & Bowers, 2006), thus requiring fewer environmental modifications than those that create specific enclosures. Additionally, two of these real-world based tasks are performed in outdoor environments (Mandolesi et al., 2009; Smith et al., 2008), although one of them also requires specific equipment (Mandolesi et al., 2009).

Regarding technology-based tasks, nine of the studies require some electronic equipment to be carried out, needing one of them a television and videotapes (Schmuckler & Tsang-Tong, 2000), a computer (Bullens, Iglói, et al., 2010; León et al., 2014; Merrill et al., 2016; van den Brink & Janzen, 2013; Yang et al., 2019), augmented reality technology (Juan et al., 2014; Rodriguez-Andres et al., 2016, 2018), and virtual reality technology (Negen et al., 2018).

Development of spatial orientation abilities

As shown in Table 1, between 7 and 12 months of age, infants appear to be sensitive to changes in visual flow and vestibular information, sources of information that are vital for proper spatial orientation (Bremner et al., 2011). Between about 4.5 months (Kaufman & Needham, 2011) and 6 months of age (Schmuckler & Jewell, 2007), infants seem to be able to show an orientation response employing coincident cues, but this result only appears if infants have previously been moved by the environment and in

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combination with egocentric information (Kaufman & Needham, 2011) or if this movement has been simulated (Schmuckler & Jewell, 2007).

Conversely, 6-month old infants do not manage to reorient themselves following a distinctive noncoincident allocentric landmark (Crowther et al., 2000). At 8.5 months of age, infants improve their orientation performance if there is one noncoincident landmark (Crowther et al., 2000) or two noncoincident landmarks (Lew et al., 2000); that is, their performance is better following an allocentric framework, rather than a purely egocentric framework. Moreover, although at 12 months old they are able to respond correctly when the only information available is self-centered, their ability to orient themselves improves if noncoincident allocentric cues are present (Lew et al., 2000). From this age and up to 18 months, toddlers are able to orient themselves toward distinctive and noncoincident allocentric landmarks as long as they have not previously been disoriented (Lew et al., 2006). Furthermore, at these ages, they manage to respond egocentrically, but with less success compared to an allocentric response (Lew et al., 2006). From 18 months to 2 years old, the ability to give allocentric responses after being disoriented improves greatly. Toddlers are be able to use different types of cues: geometric and/or visual cues, such as the color or length of the surface of the environment (Learmonth et al., 2001), cues based on linear scalar information, such as luminosity (Lourenco et al., 2009), and color-based cues (Nardini, Atkinson, et al., 2008), all of which are noncoincident landmarks. In addition, at these ages they are able to code the spatial relationships in the environment and use this information to reorient themselves (Huttenlocher & Vasilyeva, 2003) and establish spatial relationships based on a sense of "left-right" (Nardini, Atkinson, et al., 2008).

From 2 to 3 years old, children continue to use different types of noncoincident allocentric cues based on geometry, such as distances and relationships between the surfaces of the enclosures (Lee, Sovrano, et al., 2012), differential patterns with specific sizes and densities on the walls of the enclosure (Lee, Winkler-Rhoades, et al., 2012), and complex and regular octagonal environments (Newcombe et al., 2010). Moreover, starting from these ages, children will not present difficulties in reorienting following coincident landmarks (Ribordy et al., 2013; Ribordy Lambert et al., 2017) or reorienting on virtual tasks, guided by coincident and/or noncoincident landmarks (van den Brink & Janzen, 2013). However, they will still present problems in reorienting themselves in certain specific geometrical environments, such as rhomboids, despite having distinctive allocentric cues (Hupbach & Nadel, 2005), or in using landmarks related to clarity-darkness (Lee, Winkler-Rhoades, et al., 2012). Up to this point, all the landmarks used for reorientation have been proximal, but after 2 years of age, children seem to start to use distal landmarks for the first time to locate an object among four possible locations (Ribordy et al., 2013; Ribordy Lambert et al., 2017).

From 3 to 4 years of age, children can use proximal and noncoincident cues related to superficial distances and shadows to orient themselves (Lee, Winkler-Rhoades, et al., 2012), subtle geometric cues on surfaces in 3 D (Lee & Spelke, 2011), and the distance and length of the surrounding walls (Yousif & Lourenco, 2017). However, they are not yet able to establish these geometric relationships between the elements of space when they are disconnected or separated from each other. Instead, these relationships have to be explicitly shown with panels or physical elements that join the different objects (Gouteux & Spelke, 2001; Vasilyeva & Bowers, 2006). It also seems that at these ages, nongeometric proximal cues such as color (Hermer-Vazquez et al., 2001; Lourenco & Cabrera, 2015; Newcombe et al., 2010) acquire greater importance, improving performance if these colored cues are coincident (Hermer-Vazquez et al., 2001) and having a subsequent facilitating effect on reorientation in the absence of landmarks (Lourenco & Cabrera, 2015). At these ages, children seem to take advantage of "left-right" spatial relationships for reorientation as well (Newcombe et al., 2010).

Although the preference for using coincident and/or proximal cues continues if they are available (Waismeyer & Jacobs, 2013), at 3 years of age they can use distal allocentric landmarks more successfully (Nardini et al., 2006; Smith et al., 2008). However, not all studies agree with these results at such an early age (Leplow et al., 2003), where children obtain better performance using proximal rather than distal cues. Another issue that seems to improve allocentric orientation at these ages is allowing locomotion and self-movement, either real (Leplow et al., 2003) or virtually simulated (Negen et al., 2018). In fact, when the movement of 3-year-old children is not allowed, findings show that they are not able to use geometric proximal cues, but only egocentric responses (Gouteux et al., 2001). Other relevant variables that promote the use of allocentric orientation are the three-dimensionality of the target locations—instead of two-dimensionality—and maintaining the stability of the spatial relationships between these possible locations and the surrounding environment (Lee & Spelke, 2010), as well as the size of the environment or place where the task is carried out because it seems that at these ages they are not able to use distinctive allocentric cues when the task is performed in small rectangular enclosures (Learmonth et al., 2002).

The aforementioned aspects continue to improve from 4 to 5 years of age. At these ages, children can establish spatial relationships between separate objects when spatial relationships between the objects are not explicitly shown, progressively improving with age (Vasilyeva & Bowers, 2006) and guided by a distinctive and proximal landmark in large environments with regular characteristics (Newcombe et al., 2010). In addition, they seem to use proximal geometric landmarks with greater efficacy (Gouteux et al., 2001). However, they are still unable to integrate them with distal allocentric information (Hupbach & Nadel, 2005).

Regarding the use of distal information, some authors report a predominance of its use in some cases (Hupbach & Nadel, 2005), whereas others describe better performance with proximal cues (Leplow et al., 2003), but an inability to use distal information until more advanced ages persist. The use of nongeometric landmarks, such as color, which is reported to be initially used in combination with other distal environmental cues, also becomes increasingly important, as children may reorient themselves by nongeometric properties by forming direct associations between a hidden object, the distinctive color of the landmark and environmental stimuli (Gouteux et al., 2001). In addition, previous spatial learning based on color cues can be transferred and generalized to untrained or unexplored environments (Twyman et al., 2007). Although at these ages children can integrate different types of environmental cues, such as proximal nongeometric landmarks with distal stimuli (Gouteux et al., 2001), some authors disagree on this point. They argue that better performance is found at these ages only in the presence of allocentric landmarks, compared to the presence of both egocentric and allocentric cues (Nardini, Jones, et al., 2008). Thus, children at these ages seem to perform better using allocentric cues (based on landmarks) than egocentric cues (based on auto-locomotion), but in addition, the performance of these children is worse when both types of cues are available, indicating that they are not yet able to integrate them, unlike adult subjects (Nardini, Jones, et al., 2008). Thus, it could happen that when children are provided with a unique distinctive and proximal cue, as well as when self-locomotion is not required and there is no disorientation procedure, they can associate this cue with the environment (Gouteux et al., 2001). On the other hand, they would still show difficulties in more complex tasks, where the child must simultaneously take into account their own movements and the available environmental landmarks (Nardini, Jones, et al., 2008). Limitations in self-movement during spatial orientation tasks seem to be less relevant after 4 years old: from these ages on, children can use more distal geometric and nongeometric cues to reorient successfully, despite limiting their freedom of movement in small enclosures (Learmonth et al., 2008). It also seems that the absence of movement during a virtual task does not impede reorientation based on distal allocentric cues (Negen et al., 2018). Although spatial orientation studies in children do not usually find gender differences among participants, on an allocentric task that uses distal landmarks, at younger ages (4 to 5 years) girls show a similar performance to that of older boys (5 to 5.5 years) (Mandolesi et al., 2009).

From age 5 onward, children's orientation skills reach high performance levels. At these ages, children are less limited by the size of the enclosure where the task is carried out, still finding better orientation in larger enclosures at 5 years old (Learmonth et al., 2002), but the size of the area does not affect performance at around 6 years of age (Learmonth et al., 2002, 2008; Smith et al., 2008). There are no longer difficulties in the management of proximal geometric cues (Nardini et al., 2006) or a preference for the use of proximal cues versus the use of distal cues (Bullens, Nardini et al., 2010; Hupbach & Nadel, 2005), although the use of proximal or local landmarks are associated with greater success in reorientation (Bullens et al., 2011; Smith et al., 2008). Moreover, when there is a choice between one strategy or the other, they perform better on virtual tasks with the egocentric strategy than with the allocentric one at these ages (Bullens, Iglói, et al., 2010).

Six-year-old children show an improvement in their spatial learning when they navigate in virtual environments with low difficulty levels and using distal cues (León et al., 2014) Also, on these tasks, 6-year-old boys perform better than girls (León et al., 2014). Moreover, at this age, some authors found that children can successfully utilized process of integration across different scales, when distal landmarks need to be integrated with proximal locations (Smith et al., 2008). It seems that they code locations at both proximal and distal spatial scales in allocentric coordinates (Smith et al., 2008). However, other authors

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found that this is not possible until 7 years of age (Leplow et al., 2003). However, the procedures of these studies are different. In Smith et al. (2008), the tracks always remained in the same place and the task was done in an open environment. In Leplow et al. (2003), the proximal landmarks were rotated coming into conflict with the distal ones and the task took place in a circular and closed environment. From these ages, children can orient themselves with relative efficacy; therefore, the interest of research is to test how much spatial information in the environment they are capable of retaining. The results from studies on this topic are varied. For example, using distal cues, some studies have found that 5-year-old children are able to remember between 2 and 3 locations among 18 possible locations (Ribordy et al., 2013; Ribordy Lambert et al., 2017), but others have found that at 5 and 6 years of age, they only remember 2 locations among 5 possible locations, but they are not able to remember 4 locations among 9 possible locations (Pentland et al., 2003). When both distal and proximal landmarks are available, children are not able to remember the position of 3 objects within a virtual environment at 5 and 6 years old (Rodriguez-Andres et al., 2016, 2018).

Exclusively using the egocentric orientation, 5 and 6-year-old children were able to locate 1 object from 2 locations and 2 objects among 4 locations (Juan et al., 2014). Therefore, we can conclude that the number of possible locations does not seem to be as relevant as the amount of information to be remembered. Thus, it seems that in children under 6 years old, the topographical span, that is, how much spatial information we can remember in the surrounding environment, is around 2 items, and this increases successively at different ages (Piccardi, Leonzi, et al., 2014; Piccardi et al., 2015). In addition, from the age of 6, progressive knowledge of space-related vocabulary and grammar will help to improve landmark-based performance throughout childhood (Piccardi et al., 2015). It is also worth mentioning that from age 6 to 7, the management of egocentric and allocentric spatial strategies will continue to improve during childhood, adolescence, and adulthood, and then progressively decrease in the elderly (Ruggiero et al., 2016). In addition, from these ages, it has been possible to verify that other variables such as verbal memory and spatial skills influence performance in allocentric orientation (Merrill et al., 2016). Although it has been demonstrated that children can effectively use allocentric cues at this age, they are not yet able to use metric information, such as the length of a corridor, to reorient themselves appropriately (Yang et al., 2019).

Discussion

We found that the current interest in spatial orientation assessment in preschool children favors allocentric spatial orientation tests instead of egocentric spatial orientation tests. We should also highlight that on many of the assessment tasks, egocentric responses are considered nondesirable for solving the task. Because the egocentric framework is the first to emerge during child development (Acredolo, 1978), most of the researchers have probably focused on finding out when children start using allocentric cues for the first time. However, this lack of interest in the egocentric framework in recent literature is striking, taking into account that following environmental knowledge acquisition (Siegel & White, 1975), the functional use of landmarks combined with egocentric information - route knowledge-, as well as the creation of mental maps for navigation—survey knowledge—develop later in childhood, not until 7 years old (Overman et al., 1996). All of this indicates that, given that the egocentric framework develops earlier (Acredolo, 1978; Acredolo & Evans, 1980; Piaget & Inhelder, 1967), the number of articles that study this frame of reference should be greater at the earliest ages, and they should focus on the study of the allocentric framework as the target ages approach 7 years. Conversely, it is also worth mentioning that the lack of tests to assess the egocentric framework during early childhood complicates the detection of potential alterations in this capacity at these ages, which, as previously mentioned, can help to diagnose children with developmental alterations earlier, especially those with topographical developmental disorientation (Bianchini et al., 2014; Conson et al., 2018; Iaria & Barton, 2010; Iaria et al., 2009, 2005; Nemmi et al., 2015; Palermo, Piccardi, et al., 2014).

Regarding allocentric tasks, the use of noncoincident cues outpaces the use of coincident cues. Surprisingly, most of the tasks analyzed in the present review that include coincident landmarks assess 3-year-old children or older (Gouteux & Spelke, 2001; Gouteux et al., 2001; Hermer-Vazquez et al., 2001; Smith et al., 2008; Twyman et al., 2007; Vasilyeva & Bowers, 2006; Waismeyer & Jacobs, 2013), and only two evaluate coincident cues under the age of two (Kaufman & Needham, 2011; Schmuckler & Jewell, 2007). These results are surprising, taking into account that in regular development, coincident cues

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are used before noncoincident landmarks (Acredolo, 1978; Acredolo, Adams, & Goodwyn, 1984; Rieser, 1979). Therefore, it seems that the natural developmental course of allocentric evaluation would be resolved by including more coincident cues in the first stages of child development and, subsequently, including noncoincident landmarks in the assessment protocols for the evaluation of older children. However, studies have also observed that the preference for coincident cues extends to 4-year-old children (Waismeyer & Jacobs, 2013), and so it seems reasonable to continue to include these kinds of landmarks in spatial orientation tasks for preschool-aged children. Conversely, the use of proximal cues on allocentric tasks surpasses the use of distal cues. A greater presence of proximal cues is expected on experimental tasks because all the studies that only use this type of landmark are carried out in clearly delimited and closed enclosures, preventing access to remote cues. For this reason, the tasks that are carried out in virtual environments (Bullens et al., 2011; León et al., 2014; Merrill et al., 2016; Rodriguez-Andres et al., 2016, 2018; van den Brink & Janzen, 2013; Yang et al., 2019), outdoors (Mandolesi et al., 2009; Smith et al., 2008), or in less encapsulated spaces (Nardini et al., 2006; Pentland et al., 2003; Ribordy et al., 2013; Ribordy Lambert et al., 2017; Vasilyeva & Bowers, 2006) are those that most frequently use distal landmarks. Thus, distal cues are more likely to be included when the task takes place in open environments rather than small rooms.

The examination of the recent literature shows that researchers consider locomotion and/or self-movement to be a relevant variable to take into account for spatial orientation assessment in preschoolers, as almost all of them include it in their experimental tasks. At very early ages, the first locomotor capacities—involved in crawling—have been associated with improvements in spatial abilities (Acredolo et al., 1984). Being able to move around our surrounding environment allows us to know and memorize the space from different perspectives, and this early familiarization allows us to orient ourselves more effectively (Kaufman & Needham, 2011). Moreover, the studies that manipulate the child's ability to move freely, developing spatial orientation in small enclosures, find worse results in children from 3 to 5 years old when they limit their movement possibilities (Learmonth et al., 2008).

However, because orientation requires movement around the surrounding space, it seems clear that to achieve greater functional validity, it is necessary to allow children's movement even after this age. For this reason, we found that the tasks in which the participant remains static are the ones for infants or toddlers—even if they are old enough to crawl—or those performed on the computer for older ages. Even if the child does not really move, we need to take into account the existence of simulated movement in virtual tasks. Thus, although in many tasks there is no real movement, if this simulated movement is present, compensated by the apparatus or by the virtual task procedure, we should not exclude the influence of real locomotion on their results. However, in our knowledge, the comparison of simulated and real movement was not studied, making it necessary to develop new research in this direction.

Moreover, we need to consider that perceiving our own movements during spatial orientation tasks is not the only relevant information that is present in real environments: vestibular and proprioceptive information, as well as the visual flow, are also present in our daily orientation tasks (Banta Lavenex et al., 2011; Piccardi et al., 2008), and many computerized spatial tasks cannot take this information into account. Therefore, spatial tasks in real environments make it possible to perceive and upload our own movements, take into account the position of the body and the head, and be aware of our own equilibrium, and so forth, so they could be the best option for replicating the usual conditions of spatial orientation, showing greater ecological validity in its evaluation. However, including some new technologies, such as the use of realistic and immersive virtual environments that allow freedom of movement by the user (Negen et al., 2018) or the use of augmented reality in real environments (Juan et al., 2014), could be great future alternatives with high functional relevance because they combine the advantages of using new technologies with the information normally available in spatial orientation.

Functionality or ecological validity of the task is another variable that we need to take into account in order to include some of these tasks in clinical neuropsychological assessment. That is, when selecting our assessment protocol, it is important to consider whether the task is capable of reproducing, at least partially, the natural conditions where spatial orientation occurs. Therefore, the tasks that seem closer to daily orientation activities are those that take place outdoors, in wide open spaces. However, the intrinsic characteristics of these tasks make them difficult to use. They have to be conducted in a specific large and natural space. Therefore, to conduct these tasks, it is

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necessary to interrupt the usual neuropsychological assessment, which normally takes place in a clinical setting. In addition, they are difficult to standardize and replicate, making their application difficult in a standard neuropsychological evaluation. Tasks that take place in a smaller room or enclosure lose functionality but gain in standardized application. However, it is necessary to consider that some of these tasks have the disadvantage of requiring some type of equipment or specific environmental modification (large curtains or panels in most cases). Finally, tasks based on new technologies are the simplest to apply and include in routine neuropsychological assessments, but they probably have less relationship with day-to-day spatial orientation and, therefore, are the least functional. Tasks that use new technologies but achieve greater functional validity due to mobility or other characteristics they provide to participants have the disadvantage of requiring specific and expensive apparatus, such as augmented reality or virtual reality equipment.

Limitations

It is necessary to point out the lack of consensus in the terminology used in spatial orientation tasks: we found terms such as self-reference, idiothetic, response learning, and so forth, referring to the use of the egocentric spatial orientation, and terms such as Euclidean properties, allothetic, place learning, and so forth, referring to the use of the allocentric spatial orientation. Even the concept of "spatial orientation" is often referred to in terms of "spatial memory," "reorientation," or "spatial navigation." This divergence in the terms used can make it difficult to obtain relevant bibliographical references. Moreover, it is important to mention that the main aim of some of the articles analyzed in the present review was not to assess spatial orientation *per se*, but rather, for example, the ability to use a map to transfer 2D information to 3D (Vasilyeva & Bowers, 2006) or assess the topographical span (Piccardi, Leonzi, et al., 2014; Piccardi, Palermo, et al., 2014). In addition, other studies have shown interest in verifying or refuting geometry module processing (Gouteux & Spelke, 2001; Gouteux et al., 2001; Hermer-Vazquez et al., 2001; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Learmonth et al., 2002, 2001, 2008; Lee & Spelke, 2010, 2011; Lee, Winkler-Rhoades, et al., 2012; Lew et al., 2006; Lourenco et al., 2009; Lourenco & Cabrera, 2015; Nardini, Atkinson, et al., 2008; Nardini et al., 2006; Newcombe et al., 2010; Twyman et al., 2007; Vasilyeva & Bowers, 2006; Yousif & Lourenco, 2017), an innate ability, shared with other vertebrate animals, that employs geometrical features in encapsulated environments to successfully maintain correct orientation in space (Cheng & Newcombe, 2005). The way geometry is used throughout the development of spatial orientation is undoubtedly a subject of vital importance, but it is probably a topic too specific to focus on in a neuropsychological evaluation and its subsequent diagnosis. Despite this, all these studies include tasks that require spatial orientation abilities, and for this reason they have been included in the present review.

Another possible limitation that we currently find in spatial orientation researches in childhood is the difficulty in establishing the development of egocentric and allocentric frames of reference. That is, that the authors choose a certain age range does not mean that the measured ability has not emerged before; for example, that authors assess a function after 5 years, but this is actually already present in children of 4 years. Thus, it could happen that the course of development of the spatial orientation shown in the present study does not correspond exactly with the ages when these capacities emerge and improve, but at lower ages that have not been measured in the original studies. For this reason, it could be recommendable in future researches to try to expand these evaluation tasks for younger ages.

We also need to highlight that the classification followed in the present review presents certain controversies. First, some authors do not clearly mention the frames of reference used in the solution of their experimental tasks, making it difficult to classify them in egocentric and/or allocentric terms. Regarding cue use, the differentiation between coincident cues (coding of the distinctive characteristics of the location) and noncoincident cues (coding of the target location in terms of its relationship with other reference points) seems clear, whereas the difference between proximal and distal cues is more diffuse. In spatial memory paradigms in rodents, taking into account the relative size of the animal vs. the size of the elements for the task—labyrinths and cues—it seems quite clear that the distal landmarks are those that are located outside the labyrinth, that is, those that do not vary their relative position while the organism moves (O'Keefe et al., 1978). This does not occur with spatial orientation in humans. As we have seen previously, many of the tasks that employ cues classified as distal are performed in closed rooms and only a few in open spaces. Therefore, it seems necessary to

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reconsider the extent to which we can talk about a distal cue when it is located a few meters away from the participant.

Conclusion

The purpose of the present review was to assess and summarize recent literature on egocentric and allocentric spatial orientation assessment in children less than 6 years of age. Results revealed a wide variety of tasks for the evaluation of spatial orientation at these early ages.

We can conclude that spatial orientation starts early in development, with the egocentric framework being the first to appear, as well as allocentric orientation using coincident landmarks. Infants of 4.5 months old are able to orient themselves with coincident proximal landmarks if they previously had the chance to know the environment from different points of view. Later, infants of 8.5 months old use noncoincident landmarks for the very first time, and these cues continue to guide the toddler's orientation from 12 to 18 months, if they have not been disoriented, and from 18 to 24 months if they have changed their position, starting to use geometrical and nongeometrical cues as well. From 2 to 3 years of age, although children continue to use different kinds of noncoincident landmarks, they show the use of distal cues to reorient themselves. From 3 to 4 years old, children's reorientation improves with the use of different proximal and distal noncoincident landmarks. Later, from 4 to 5 years old, they are able to compensate for the lack of self-motion in enclosed spaces or establish a spatial relationship between discontinued elements, and it seems that they start to integrate different types of spatial cues. From 5 years old onward, they do not show any problems with geometric, nongeometric, distal or proximal cues, they improve their ability to integrate difference sources of spatial information and they are able to remember more spatial information in their memory.

We have observed, despite this wide variety of tests, a lack of tasks to analyze all the relevant characteristics of daily spatial orientation in preschool ages. That is, whereas we have many tasks for allocentric evaluation, with different types of cues and aimed at different ages, we find that the current spatial orientation tasks for preschoolers fail to evaluate the egocentric framework, which highlights the need to develop tasks for the evaluation of the egocentric spatial orientation at early ages. Although in our daily activity, spatial orientation depends on the combination and use of both frameworks, it would be of great interest to have tasks available to evaluate egocentric and allocentric orientation separately. These tasks can detect developmental alterations in the management of a specific framework that could occur in neurological diseases or developmental problems that affect the main brain areas that participate in spatial orientation, such as hippocampal areas, temporal, parietal and temporal cortex, thalamus, and striatum. Some other relevant issues in spatial orientation assessment, such as whether children are allowed to move during the tasks or whether spatial tasks are carried out in real environments, are present in the most of spatial orientation test. Moreover, the incipient presence of new technologies in the evaluation of spatial orientation is not negligible. Therefore, it would be advisable to continue researching in this direction with the aim of ensuring an appropriate ecological validity of these procedures.

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The authors declare that they have no conflict of interest.

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