Egocentric and allocentric spatial memory in young children: a comparison with young adults

Journal:	*Infant and Child Development*
Manuscript ID	ICD-20-0182.R1
Wiley - Manuscript type:	Research Article
Keywords:	spatial orientation, memory, egocentric, allocentric, development

Abstract:	The most used frames of reference in spatial memory, which allows us to move through the environment, are the egocentric, related to one's own perspective, and the allocentric, based on environmental cues. Although many assessment tasks have been proposed, tests that allow to evaluate the two frames of reference separately and compare adults and children are scarce. Our aim was to assess egocentric and allocentric spatial orientation in children (5-7 years old) and young adults, comparing between ages, frames of reference and gender. The Egocentric and Allocentric Spatial Memory Tests were used. Adults perform better than children on both tasks. Children perform equally in both frames of reference, but adults are more efficient on the Allocentric test. Gender does not seem relevant in the performance of either group. Overall, egocentric and allocentric spatial memory are not fully developed at the age of 7 and children do not master any strategy above the other.

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Abstract

The most used frames of reference in spatial memory, which allows us to move through the environment, are the egocentric, related to one's own perspective, and the allocentric, based on environmental cues. Although many tasks have been proposed, those that evaluate the two frames of reference separately and compare adults and children are scarce. Our aim was to assess egocentric and allocentric spatial orientation in young children and young adults, comparing between ages, frames of reference and gender. The Egocentric and Allocentric Spatial Memory Tests were used. Adults perform better than children on both tasks. Children perform equally in both frames of reference, but adults are more efficient on the Allocentric test. Gender does not seem relevant in the performance of either group. Overall, egocentric and allocentric spatial memory are not fully developed at the age of 7 and children do not master any strategy above the other. ~~The tasks used in the present study allow to evaluate the performance of adults and children on both types of spatial orientation.~~

Highlights:

- Do school-aged children reach adults performance in egocentric and allocentric spatial memory?
- Two experimental tasks, Egocentric and Allocentric Spatial Memory, were used for assessment. Significant differences were found between children from 5-to-7 years and adults.
- Egocentric and allocentric frameworks are not fully developed at 7 years. Children may not rely on one specific framework for their orientation.

Keywords: Spatial orientation; memory; egocentric; allocentric; development.

1. Introduction

Humans employ their spatial memory and orientation abilities to move through their environment without getting lost, using two frames of reference for this purpose: the egocentric and the allocentric frame. Egocentric orientation takes into account our own point of view and how it changes while we are moving, while allocentric orientation employs external stimuli independent of our position (O'Keefe & Dostrovsky, 1971; Ruggiero, Iachini, Ruotolo, & Senese, 2009). Therefore, the egocentric framework is related to the capability to monitor the body's directions, turns and movements, involving the kinesthetic, vestibular and optic systems (Montello, 2005; Newcombe, Huttenlocher, Drummey, & Wiley, 1998), while the allocentric framework is associated with identifying environmental landmarks, and remembering and recognizing them to create mental maps (Burgess, Maguire, & O'Keefe, 2002; Montello, 2005; O'Keefe, Nadel, & Lynn, 1978). The acquisition of such spatial knowledge implies the processing of spatial information (Lopez, Caffò, & Bosco, 2019), as well as its codification, storage and retrieval, allowing to create spatial mental representations which contains not only the allocentric landmarks, but the distances, positions and directions between them (Lopez, Postma, & Bosco, 2020). Besides, both strategies are integrated into our daily lives, along with other cognitive functions, to provide us with functional spatial navigation.

Different studies, performed in both virtual and real environments, have tried to focus on the type of strategies that are preferred or used in a more accurate way during childhood compared to different periods of life. Some studies have used certain experimental tasks to verify which strategy, egocentric or allocentric, emerges spontaneously throughout the task or which strategy is applied with a higher success rate. In this regard, we found comparisons between children and young adults (Hu, Yang, Huang, & Shao, 2018) and between children, adults and older adults (Bohbot et al., 2012). However, these studies show contradictory results: young adults either perform better in the egocentric framework (Hu et al., 2018) or that they do not show a clear preference (Bohbot et al., 2012). Besides, children may show either spontaneous use of the allocentric framework (Bohbot et al., 2012) or the egocentric (Hu et al., 2018). Other studies have focused on evaluating which orientation strategy allows children to perform better on the experimental task. It seems that children rely more on the egocentric strategy (Yang, Merrill, & Wang, 2019) despite being able to employ allocentric cues when task resolution requires it at 9 and 10 years of age (Yang et al., 2019), as well as at the ages of 3, 4 and 5 (Leplow et al., 2003). In addition, other studies focus on designing experimental tasks to evaluate egocentric and allocentric frameworks separately and have observed how the performance in each strategy evolves throughout life (Ruggiero, D'Errico, & Iachini, 2016). The findings suggest that the egocentric perspective is usually more accurate for all ages, although the experimental procedure that was used does not measure spatial memory itself, but rather the emission of spatial judgments from a static position. Thus, it seems that the literature that tries to directly compare the execution of the egocentric and allocentric framework in children compared to adults using experimental tasks that are methodologically similar but that evaluate each process separately is scarce.

In relation to the development of spatial orientation in childhood (see Fernandez-Baizan, Arias, & Mendez (2019) for a complete review), previous studies show that although some allocentric cues can be used earlier, this strategy becomes more functional from the age of 2, with children being able to reorient themselves allocentrically following various types of cues (Huttenlocher & Vasilyeva, 2003; Learmonth, Newcombe, & Huttenlocher, 2001; Lourenco, Addy, & Huttenlocher, 2009; Nardini, Atkinson, & Burgess, 2008). However, it seems that it is at the age of 5 that this skill is most efficiently used, with children being able to reorient themselves in different shaped and sized enclosures, and guide themselves by clues closer to their position or more distant (Bullens, Nardini, et al., 2010; Hupbach & Nadel, 2005; Learmonth, Nadel, & Newcombe, 2002; Smith et al., 2008). In terms of the framework development, it seems that to reach a similar maturity to the one expected of an adult, the allocentric framework develops from early childhood to at least the age of 7 (Bullens, Iglói, Berthoz, Postma, & Rondi-reig, 2010; Leplow et al., 2003; Overman, Pate, Moore, & Peleuster, 1996). As for the egocentric framework, despite being the first to emerge in childhood (Acredolo, 1978), its development has been much less studied compared to the allocentric one. However, other research suggests that by the age of 5, children could reach a similar performance to the one shown by adults (Hu et al., 2018). Therefore, we can expect to find a significant improvement in spatial orientation skills in childhood, based on previous literature probably between the ages of 5 and 7, and a possible predominance of the egocentric strategy at these ages.

Another important variable to consider in spatial orientation performance is gender. Previous literate in adulthood find that men generally outperform women (León, Tascón, & Cimadevilla, 2016; Persson et al., 2013; Picucci, Caffò, & Bosco, 2011; Tascón, García-Moreno, & Cimadevilla, 2017), although such execution seems to depend on numerous variables, such as the type of cues available, previous experience and/or training in these skills, familiarity with the environment, etc. (Banta Lavenex & Lavenex, 2010; de Goede & Postma, 2015; Nori et al., 2018; Piccardi et al., 2008; Verde et al., 2015). In contrast, these gender differences are not clearly established in children, finding contradictory results regarding the childhood period (Nazareth, Huang, Voyer, & Newcombe, 2019). Some research results point to better performance of boys (León, Cimadevilla, & Tascón, 2014; Newhouse, Newhouse, & Astur, 2007; Rodriguez-Andres, Mendez-Lopez, Juan, & Perez-Hernandez, 2018), and others to similar performance between boys and girls (Juan, Mendez-Lopez, Perez-Hernandez, & Albiol-Perez, 2014; Leplow et al., 2003; Ribordy, Jabès, Banta Lavenex, & Lavenex, 2013; Rodriguez-Andres, Juan, Mendez-Lopez, Perez-Hernandez, & Lluch, 2016). According to the Nazareth's meta-analysis (2019), it appears that gender differences in childhood tend to be generally small, while such differences increase after puberty and across adolescence.

Assessing allocentric and egocentric frames of reference separately is particularly relevant not only with the objective of understanding their development and average functioning, but also to use it as a tool to evaluate different populations with pathologies. In children, certain clinical populations such as spinal muscular atrophy (Rivière & Lécuyer, 2002) or perinatal stroke (Murias et al., 2017) show an adequate spatial memory for their developmental stage. Nevertheless, difficulties in both egocentric and allocentric frameworks have been found in developmental topographical disorientation (Iaria & Barton, 2010) and in Williams syndrome (Bernardino, Mouga, Castelo-Branco, & Van Asselen, 2013; Broadbent, Farran, & Tolmie, 2014), while in Down syndrome (Lavenex et al., 2015), in cerebral palsy (Belmonti, Fiori, Guzzetta, Cioni, & Berthoz, 2015), in fetal alcohol syndrome (Hamilton, Kodituwakku, Sutherland, & Savage, 2003) and in children born prematurely (Fernandez-Baizan, Alcantara-Canabal, Solis, & Mendez, 2020) a worse allocentric-based orientation is found, which, as we have already commented, has been the most studied. However, it still remains unclear whether these populations show simultaneous deficits in the egocentric frame. Therefore, clinicians could benefit from assessing each framework separately to understand whether or not a patient with a certain pathology shows problems in orientation when using a specific frame. This in turn would alter the aims and methodology of intervention accordingly.

This study aimed to compare the performance of young children (5-to-7 years) and young adults on egocentric and allocentric assessment tests carried out in real but controlled environments, in order to provide an ecological and functional measure of spatial orientation abilities, taking into account the gender of the participants. Our hypothesis was that younger children would show the lowest performance of all the groups in both egocentric and allocentric tasks, whereas older children would obtain similar scores to adults, but without reaching their level. Moreover, we hypothesized that men would perform better than women, but scores would be similar for boys and girls. We also aimed to compare the two frameworks, egocentric and allocentric, in both groups. Our expectation was that egocentric performance would be better than allocentric performance in children and young adults.

2. Material and method

2.1. Participants

The sample was composed of 55 young adults (range: 18-32 years), who were volunteer students from the Faculty of Psychology of the University of Oviedo (Spain), and 55 children (range aged : 5-7 years5 to 7) (sociodemographic data are shown in Table 1). Exclusion criteria included intellectual disability, neurological or neurodevelopmental disorders, psychiatric problems, and any other condition that could affect test performance. Their cognitive level was tested with the Reynolds Intellectual Screening Test (RIST) (Reynolds & Kamphaus, 2003), and subjectparticipants whose levels were 85 (one standard deviation below 100 – mean value –) or below were excluded (2 children and 3 adults did not reach such criterion). Main demographic data and RIST results of the participants are shown in Table 1. Adult participants and parents or tutors of the children were informed about the study's aims and purposes, and they read and signed a written informed consent form. This study was conducted in compliance with the European

Community Council Directive 2001/20/EC and the Helsinki Declaration for biomedical research involving humans.

2.2. Material

2.2.1. Reynolds Intellectual Screening Test (RIST) (Reynolds & Kamphaus, 2003)

This test provides an estimate of the intelligence quotient (IQ) for 3- to 94-year-olds with a time of administration of 15 minutes approximately. It consists of two tasks: "Guess what", related to a verbal score, in which the participant is asked to find the accurate word for some definitions read by the examiner, and "Odd-item", related to a non-verbal score, in which the participant is asked to point out the different or incongruent image out of several pictures. For our age-groups and according to Spanish adaptation of the test, the reliability of the RIST test was between 0.87 and 0.91.

2.2.2. Egocentric Spatial Memory Test

Based on the previously published head disorientation test (Hashimoto, Tanaka, & Nakano, 2010), a squared template was used that was divided into nine squares, placed on the floor, and surrounded by four opaque panels. The size of the templates and panels varied for adults and children (105 x 105 cm templates and 280 x 250 cm panels for adults, and 90 x 90 cm templates and 180 x 180 panels for children). Different items were used for adults and children in order to favor motivation and avoid the influence of attention span: three cards with geometric figures for adults and two cartoon pictures for children (Figure 1.A). The Egocentric test was divided into two parts. In part A, the participant was placed in the center of the matrix. The instructions given to the participant were: "We are going to do a memory task. I am going to place each of these cards – while the examiner showed them to the participant– in some of the squares around you, and you have to remember the location of these cards: each card should be placed back in its corresponding square". After 10 seconds of delay, he/she had to place the items in their original position. In part B, the instructions were: "Now, we are going to continue with this task. Like before, you have to remember the location of these cards that I am showing you. However, I am now going to move you; that is, I'm going to turn you around, and you have to then place each card back in its corresponding square". Then, after the items had been shown on the template for 10 seconds, the subjectparticipant was rotated (90 or 180º to the right or to the left), and were asked to place the items in their positions again without turning around. In this way, the participant had to not only remember the position of the cards (front, back, left, right, etc.), but also monitor the changed egocentric viewpoint to be able to readjust the initial egocentric memorization to the new position. Therefore, in part A, the participant remains static (same point of view), whereas in part B, the participant memorizes the items in one position, but relocates them to another new position (point of view changes). Thus, part A assesses visuospatial short-term memory in a three-dimensional environment, whereas part B evaluates an egocentric response because the landmarks are hidden by the panels. Children perform 10 trials (5 in part A and 5 in part B), and adults perform 20 (10 in part A and 10 in part B). The percentage of correct responses were calculated for each group. Internal consistency for Egocentric part A was 0.82 and for part B was 0.71.

2.2.3. Allocentric Spatial Memory Test

Based on the Morris water maze (Vorhees & Williams, 2006) adapted for humans, a round template with eight squares surrounding its perimeter (95 cm. and 65 cm. in diameter for adults and children, respectively) was used. This test was conducted in a rectangular room with furniture and objects in the participant's sight. The same cards as in the Egocentric Spatial Memory Test were used for this task, and the participant was also asked to remember their positions on the squares of the template (Figure 1.B). On this test, items were located in the squares on the template. The examiner gave the participant the following instructions: "Now, on this task, you also have to remember the location of the three previous cards: each must go in its corresponding square. After that, I am going to ask you to cover your eyes, and I am going to move you; that is, I'm going to guide you in walking around the template until you reach a new position. Once we get there, you have to remove your blindfold and put the cards back in their place". After 10 seconds of memorizing, the participant was blindfolded and moved along the circular template to a different location. From this new position, s/he had to position the items the way they were before, being allowed in this case to move again through the circular template. Therefore, the ~~subject~~participant memorized the items' location in one position, but s/he was then moved, changing his/her point of view. However, and contrary to the Egocentric test, landmarks in the room were available, and the participant could use them to reorient him/herself. Therefore, the participant had not only to memorize the position of the cards, but also to look at some of the environmental cues available in the room in order to be able to locate the cards properly after being moved. The Allocentric test is divided into three blocks with a maximum of 4 trials, where the position of the items which participants have to memorize always being the same across trials. The percentage of correct responses were calculated for each group. Internal consistency for Allocentric test was 0.78 (for block 1, 0.71; for block 2, 0.88; and for block 3, 0.75).

2.3. Procedure

~~Subject~~Participants were tested individually by trained psychologists. The assessment were carried out in the following order: the RIST test (Reynolds & Kamphaus, 2003) and the Egocentric and Allocentric Spatial Memory Test in the adult (Fernandez-Baizan, Arias, & Mendez, 2019) and in the child versions (Fernandez-Baizan, Nuñez, Arias, & Mendez, 2020). The entire procedure was administered in a 30-minute session carried out in the Faculty of Psychology and in local primary schools in Oviedo, Spain. Data were collected between 2017 and 2019. ,

2.4. *Statistical analysis*

Analyses were performed with IBM SPSS Statistics 24. The minimum sample size was 69 (Confidence interval 90%, Margin of error 10%). After checking the normality and homogeneity of our sample with Saphiro-Wilk and Levene, parametric statistics were used. A one-way ANOVA (Age groups) was used to compare IQ tests between groups and a two-way ANOVA (Age group x Gender) was conducted to compare performance on the spatial memory test. Bonferroni's post hoc test was used to analyze differences between Age groups. ANCOVA analysis (Age group x Gender) with a covariation of the effect of Egocentric Part A and whether the participant performed better on Egocentric or Allocentric task (Strategy performance) was also used to compare groups regarding the spatial tasks. A bivariate Pearson correlation analysis was applied to verify relationships between the Egocentric and Allocentric test parts and blocks and between these spatial memory tests. Repeated-measures ANOVAs were used to compare the different parts and blocks of the Egocentric and Allocentric tests, also considering the Strategy performance factor. The Cohen's d effect size (d) or squared Eta (η^2) was reported for group comparisons. Differences were considered significant at $p<0.05$.

3. Results

First, a one-way ANOVA analysis (Age group) was carried out. The Age group variable did not show significant differences for the RIST test ($F_{3,106}=3.879$; $p=0.061$; $\eta^2=0.099$).

Second, a two-way multivariate ANOVA analysis (Age group x Gender) was conducted. For the Group variable, we found significant results for Egocentric Part A ($F_{3,102}$=4.334, p=0.006, η^2=0.113), Egocentric Part B ($F_{3,102}$=9.347, p<0.001, η^2=0.216), total Allocentric ($F_{3,102}$=19.033, p<0.001, η^2=0.359), Allocentric block 2 ($F_{3,102}$=10.334, p<0.001, η^2=0.233), and Allocentric block 3 ($F_{3,102}$=13.639, p<0.001, η^2=0.286). Using ANCOVA analysis (Age x Gender), with a covariation of the results of Egocentric Part A due to its potential influence, these significant results according to Age were maintained. The Bonferroni's test revealed significant differences in the Egocentric part A scores between the adult group and the 5-year-old group (p=0,016). For the Egocentric part B, these differences were found between adults and all the groups of children: 5-year-olds (p<0.001), 6-year-olds (p=0.001), and 7-year-olds (p=0.014). The same between-group results were found for the total Allocentric scores, where adults showed significant differences compared to 5-year-olds (p<0.001), 6-year-olds (p<0.001), and 7-year-olds (p=0.002) (Figure 2.A). In the second block of the Allocentric task, differences were found between adults and the 5-year-old group (p<0.001), whereas in the third block, significant differences were obtained between adults and the 5-year-old (p<0.001), 6-year-old (p=0.049), and 7-year-old (p=0.049) groups. Allocentric block 1 did not show significant differences between Groups (p=0.105) (Figure 2.B). No significant results were found for Gender or the Group x Gender interaction.

Pearson correlations showed that spatial orientation tasks are not related in the adult group; that is, there is no significant association between Egocentric part A, Egocentric part B, and the Allocentric tests. In the children's group, we observed that Egocentric part B was significantly related to the total Allocentric score (r=0.305, p=0.024), although Egocentric A was not significantly correlated with the other tasks.

Several repeated-measures ANOVA (Gender as between-group factor) were conducted in order to compare spatial orientation tasks separately in each group. In the adult group, repeated-measures ANOVA (Egocentric A vs Egocentric B) revealed significant differences between parts A and B ($F_{1,53}$=45.834, p<0.001, η^2=0.464). In addition, when performing a repeated-measures ANOVA (Total Egocentric vs. Allocentric), significant results were found on the Egocentric and Allocentric tests ($F_{1,53}$=2.567, p<0.001, η^2=0.289), with better performance on Allocentric. Finally, a repeated-measures ANOVA (Allocentric block 1 vs. block 2 vs. block 3) revealed significant differences between Allocentric blocks 1, 2, and 3 in this group ($F_{2,52}$=3.610, p=0.034, η^2=0.122). Specifically, these differences were mainly between blocks 1 and 3 (t_{54}=-2.613, p=0.011, d=0.364) (Figure 2.B). None of these comparisons revealed significant results for the Gender variable. In the groups of children, after conducting a repeated-measures ANOVA (Egocentric A vs Egocentric B), significant differences were also found between Parts A and B in 5-year-olds ($F_{1,15}$=25.672, p<0.001, η^2=0.631), 6-year-olds ($F_{1,17}$=19.711, p<0.001, η^2=0.537), and 7-year-olds ($F_{1,17}$=24.441, p<0.001, η^2=0.590). However, repeated-measures ANOVA (Total Egocentric vs. Allocentric) showed no group differences when comparing the total Egocentric and total Allocentric scores at the age of 5 (p=0.879), 6 (p=0.166), and 7 (p=0.088). Finally, in the children groups, after conducting a repeated-measures ANOVA (Allocentric block 1 vs. block 2 vs. block 3), no significant results were found between the Allocentric blocks (1, 2 and 3), and no significant outputs were observed based on Gender.

4. Discussion

In this study, we aimed to assess children and young adults on their egocentric and allocentric framework abilities by using tasks that reproduce, as far as possible, the conditions of regular spatial orientation, but in a controlled environment that allowed us to implement a standard neuropsychological evaluation protocol.

First, we observed that even though children's scores are close to those of adults, neither younger nor older children achieved the same level as adults on egocentric (part B) and allocentric orientation. Moreover, these findings do not seem to depend on a better short-term spatial memory, as these results remain equal after controlling the execution of the Egocentric part A, and neither do they seem to be related with general intelligence level, as there were no significant differences between groups for this measurement. Thus, our results indicate that spatial frames of reference evaluated separately are not fully developed by the age of 7. On the one hand, improvements in the egocentric frame have been observed in children until the age of 9 or 10 (Mendez-Lopez, Perez-Hernandez, & Juan, 2016; Piccardi et al., 2014). At these ages, their results in this framework could be comparable to those of adults (Ruggiero et al., 2016). However, other studies show that 5-year-old children reach a level of adults (Hu et al., 2018). On the other hand, although previous research point out that at 7 years of age the allocentric framework development achieves a higher level of functioning (Bullens, Iglói, et al., 2010; Leplow et al., 2003; Overman et al., 1996), these studies do not compare children and adult performance. The studies that do such comparison find that children could not reach the adult performance until the age of 10 (Bullens, Iglói, et al., 2010; Leplow et al., 2003). Therefore, our results are consistent with most of the previous studies. Not only that, but other research using tasks carried out in open-air environments has found that more advanced aspects of space navigation could mature even later, at 12 or 13 years of age (Overman et al., 1996). Therefore, it is unclear whether the results of the allocentric task may be due to a lack of complete development of this frame of reference, compared to the adult population, or to the absence of relational aspects of spatial information. It is impossible to rule out whether or not the participants also use information coming from their own organism, that is, egocentric cues, during the execution of the allocentric test. Thus, as it is pointed out in the Ekstrom review (Ekstrom, Huffman, & Starrett, 2017), as the participant moves, he/she could relate the landmark positions to his/her position, which requires an egocentric frame of reference. Even if we could minimize this effect by covering the participant's eyes during the displacements in our allocentric task, as well as removing information coming from the optical flow, we cannot discard the use of proprioceptive and vestibular signals. Thus, this lower performance in children could be due to difficulties in combining the two types of information, a skill that is already clearly present in adults. In this sense and regarding the model of environmental knowledge acquisition (Siegel & White, 1975), there is a first developmental step in which landmarks are recognized, but not implemented with directional functions, followed by a second step in which consecutive landmarks start to be integrated with self-centered information. This is a more advanced process in terms of development. Therefore, including older children in future research could help to define whether it is indeed the lack of integration between cues that keeps children from reaching the expected allocentric performance.

Taking into account the main neuroanatomical substrates of spatial orientation, it makes sense that this ability does not finish developing until children are approximately 10. Different neural networks for each of the frames of reference have been proposed by previous studies. The egocentric frame relies primarily on the caudate nucleus and parietal cortex (Cook & Kesner, 1988; Neggers, Van der Lubbe, Ramsey, & Postma, 2006), while the allocentric frame is supported mainly by the hippocampus and parahippocampus (O'Keefe et al., 1978). Furthermore, the retrospenial cortex is involved in switching from the allocentric to the egocentric frame (Vann, Aggleton, & Maguire, 2009). Although the main connections of the hippocampus with other subcortical and cortical areas are already present at the age of 4, these connections develop progressively until the age of 10 (Blankenship, Redcay, Dougherty, & Riggins, 2017). In addition, it has also been shown that global hippocampal volume still increases in late infancy, from the age of 8 until adolescence (Tamnes, Bos, van de Kamp, Peters, & Crone, 2018). During the processing of complex visual scenarios, when the integration of egocentric and allocentric spatial information is needed, it has been found that children from 7 to 11 years of age present a greater immaturity of the retrospenial cortex compared to adults (Jiang et al., 2014). In these tasks, a greater involvement of the parahippocampal areas from childhood to adult life, which is associated with successful memory formation, has also been shown (Chai, Ofen, Jacobs, & Gabrieli, 2010; Meissner, Nordt, & Weigelt, 2019). While adults and children from 7 to 12 years of age present a similar volume of the retrospenial cortex, the parahippocampal areas present less volume during this stage of childhood (Meissner et al., 2019). Finally, the progressive activation of upper parietal regions has been related to a greater specialization of episodic memory, which is found to start around the age of 12, but not younger (Ghetti & Bunge, 2012). Structurally, the parietal lobe seems to suffer the greatest decrease in cortical volume during adolescence compared to childhood (Tamnes et al., 2017).

Moreover, we observed that only the 5-year-old group scored worse than adults on visuospatial short-term memory (Egocentric part A), pointing out that 6- and 7-year-old children reached adult visuospatial memory capacities. It is worth mentioning that children performed the tasks with two items, whereas adults had three. Thus, it is possible that the number of items to remember influenced these results. However, it should be noted that the goal was to minimize the visuospatial span influence for both groups. Previous studies show that the average visuospatial span, that is, the amount of visuospatial information a child is able to memorize, at age 5 is 1.9 (Piccardi et al., 2014), and therefore the use of two items seems to be an accurate span for assessing spatial memory at that age. However, it seems plausible to increase it to almost 3 at age 7, which could be addressed in future research. In comparison with part A (static), we found that in part B (rotated) all children groups performed worse than adults. This indicates that when the egocentric viewpoint changes, and the information held in memory is updated according to the new position, the egocentric viewpoint matures at a later stage, when it is stable. Such difficulties in childhood in performing mental transformations based on rotation have been found in previous research on spatial navigation (Vander Heyden, Huizinga, Raijmakers, & Jolles, 2017) and mental rotation tasks (Wimmer, Robinson, & Doherty, 2017).

Regarding the Allocentric test, learning skills were also different according to age. Compared to adults, block 3 showed differences in all children groups, whereas block 2 only revealed difference at age 5, and block 1 did not show any differences. Therefore, these results point out that at the beginning of the task, children can apply an allocentric strategy effectively, but during the task, their performance tends to decline. Several uncontrolled factors can explain why children's achievement does not improve across blocks: lack of motivation, boredom, fatigue, or a possible proactive interference process, which is a common phenomenon throughout childhood (Kail, 2002) and in which the previous trials interfere the execution of the last ones. Moreover, none of these age differences exist among the children themselves, i.e., between the ages of 5 and 7, performance on these spatial orientation tasks seems to remain stable. These results contradict previous studies on both egocentric and allocentric orientation (Juan, Mendez-Lopez, & Perez-Hernandez, 2014; León, Cimadevilla, & Tascón, 2014; Nardini, Jones, Bedford, & Braddick, 2008; Negen, Heywood-Everett, Roome, & Nardini, 2018; Rodriguez-Andres et al., 2016). However, many of their tasks included not only children between 5 and 7, but also younger and older children, in the same group of analysis (Juan et al., 2014; Nardini et al., 2008). Moreover, it is sometimes difficult to compare the experimental procedure used with the one in the present study, for example, in the case of virtual-based tasks (León et al., 2014; Negen et al., 2018; Rodriguez-Andres et al., 2016). Nevertheless, it is also important to highlight that, despite the lack of significant results, 5-year-old children achieved a lower level of correct responses in Allocentric task compared to older children, especially in the second block, but also in the third block. These outcomes could be due to the progressive maturation of the hippocampal structures, and more specifically, the dentate gyrus. Allocentric processing requires the entorhinal cortex and its connection with CA1 area of the hippocampus (Lavenex & Banta Lavenex, 2013). Nevertheless, the dentate gyrus and its connection with CA3 area is involved in learning spatial locations that are close to one another, as it happens in our Allocentric task (Lavenex & Banta Lavenex, 2013). According to the Lavenex & Banta Lavenex's review (2013), the progressive maturation of the dentate gyrus and the hippocampal connections might improve allocentric memory and spatial location learning in children between 2 and 5 years of age.

In terms of gender, we did not obtain any differences for either adult or child participants. In the case of children, gender differences are not always found (Juan et al., 2014; Leplow et al., 2003; Ribordy et al., 2013; Rodriguez-Andres et al., 2016), although in some studies boys outperform girls (León et al., 2014; Newhouse et al., 2007; Rodriguez-Andres et al., 2018) and in others it is the other way around (Mandolesi, Petrosini, Menghini, Addona, & Vicari, 2009). There seems to be a consensus in which that differences between males and females are bigger and are found more consistently across different studies after puberty (Nazareth et al., 2019). However, the uneven distribution of boys and girls across the age groups in child samples may have influence results, contributing to the lack of significant outcomes in this matter. In the case of adults, these results are contrary to expectations, as previous studies have demonstrated the existence of certain differences, favoring males (León et al., 2016; Persson et al., 2013; Picucci et al., 2011; Tascón et al., 2017). However, it also seems that these gender differences depend on many factors, such as environmental cue availability, previous background on similar tasks, or performing the task in previously known places (Banta Lavenex & Lavenex, 2010; Nori et al., 2018; Piccardi et al., 2008) and even could depend on the task itself, as women have been found to have a better memory for locating objects than men, especially if those objects can be named (James & Kimura, 1997; Voyer, Postma, Brake, & Imperato-McGinley, 2007), which may have made them remember the position of landmarks better, as well as the items on the cards. In addition, it is necessary to emphasize that our Allocentric task for adult population is longer than the one used in the present study, and it is precisely the first and the fifth block where these gender differences emerge (Fernandez-Baizan, Arias, et al., 2019). Therefore, it may be necessary to introduce more length and difficulty into the allocentric task in order to make it sensitive to gender differences, as well as to use more abstract and unrecognizable items and landmarks.

Furthermore, we found that spatial orientation tasks are related to each other in children, but not in adults. Specifically, Egocentric part B scores are associated with Allocentric performance regarding children outcomes. This could show that adults do employ the expected strategy for each of the tasks, i.e., they use their egocentric framework in the Egocentric task and their allocentric framework in the Allocentric task, while children could have tried to use egocentric information to solve the allocentric task or vice versa, as we discussed above. Using the other framework to solve a task is not an efficient way of solving the test which may be one of the reasons that, together with the lack of development of this function according to their age, performance on these tasks was worse than that of adults.

When comparing performance on the two spatial orientations, we observe that both adults and children execute part A of the Egocentric task better than part B. These results are consistent with previous studies showing that it is easier to solve a memory task in a static position than after rotation (Vander Heyden et al., 2017). However, better performance in the allocentric frame of reference than in the egocentric is only observed in adults, whereas in children, performance is the same on egocentric and allocentric tasks. Although some studies have found that both adults and children perform better by using an egocentric point of view (Banta Lavenex et al., 2011; Hu et al., 2018; Ruggiero et al., 2016) these differences may be due to methodological issues, such as performing the task virtually (Bullens, Iglói, et al., 2010) or without locomotion by the participant (Ruggiero et al., 2016), which is important when assessing spatial memory. By comparing frames of reference, considering paradigms where it is not necessary to deal with conflicting frames, adults perform similar in both frames of reference (Hu et al., 2018). Similarly, there also seems to be some preference for a reference framework according to the country of origin. Thus, there seems to be no strong preference in European countries, and most cultures seem to use the allocentric strategy more efficiently (Goeke et al., 2015). Related to the cultural issue, there is a wide body of literature that analyzes what kind of codification is followed in different geographical places, and thus, it seems that certain tribes seem to orientate themselves by following an absolute system of coordinates (i.e., uphill or downhill) (Brown & Levinson, 1993), while in western countries, an egocentric and relative internal language predominates (i.e., front or back) (Levinson, 1997; Li & Gleitman, 2002). These findings may indicate that the data shown here may not be generalizable to all cultures, because the language that the participants use to orientate themselves has not been examined, although they all belong to the same cultural environment. Therefore, given that the literature directly comparing egocentric and allocentric frameworks is still limited and culturally dependent, it would be necessary to continue research in this direction in order to establish clear conclusions.

5. Conclusions

This study proposed two tasks of spatial orientation assessment, egocentric and allocentric, for the evaluation of children and adults, in order to compare their performance and outline a course of development of these capacities. We were able to verify that at least until the age of 7, these two frames of reference have not finished developing. Gender does not appear to be an influential factor in performance, although some methodological aspects may be influencing these outcomes. It also seems that children tend to use both types of information, egocentric and allocentric, to solve tasks, whereas in adults, the two are totally independent.

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7. Tables

Table 1. Sociodemographic data and RIST scores of the sample

	Adults (N=55)		5-years-old (N=17)		6 years-old (N=19)		7-years-old (N=19)	
Age (Mean ± SD)	20.15 ± 3.30		5.39 ± 0.45		6.45 ± 0.30		7.59 ± 0.41	
RIST (Mean ± SD)	103.69 ±10.48		108.76 ± 10.76		111.57 ± 11.16		111.89 ± 14.22	
	Male (N=30)	Female (N=25)	Male (N=6)	Female (N=11)	Male (N=7)	Female (N=12)	Male (N=7)	Female (N=12)
Age (Mean ± SD)	20.53 ± 4.07	19.68 ± 2.01	5.37 ± 0.49	5.41 ± 0.33	6.65 ± 0.19	6.21 ± 0.40	7.64 ± 0.42	7.50 ± 0.38
RIST (Mean ± SD)	107.70 ± 3.30	99 ± 7.51	113.66 ± 10.81	99 ± 7.51	111.33 ± 10.11	112 ± 13.63	114.75 ± 15.50	107 ± 11.06

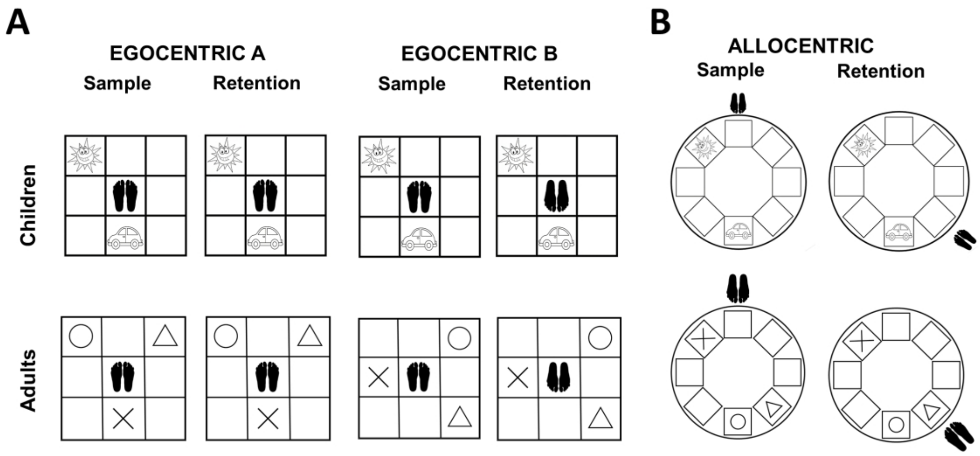
8. Figure captions

Figure 1. Example Trials from the Egocentric and Allocentric Spatial Memory Tasks for children and adults.

A) An example of sample and retention trials from Egocentric parts A and B for children and adults (B) An example of sample and retention trials from Allocentric test for children and adults.

Figure 2. Spatial orientation comparison between children and adults.

(A) Percentages of correct responses in Egocentric and Allocentric tasks for children and adults (mean + SEM). Significant differences were found between adults and children of all age groups in Egocentric part B and Allocentric, while only 5-years-old group scored lower than adults in Egocentric part A. EgoA= Egocentric part A, EgoB= Egocentric part B, Allo= Allocentric, *p<0.05, **p<0.01. (B) Percentages of correct responses in Allocentric blocks 1, 2 and 3 for children and adults (mean + SEM). Significant differences were observed between adults and 5-years-old children in second block (*p<0.001) and between adults and all groups of children in third block (&p<0.05). In adult group, significant improvement has been found between first and third block (#p=0.011).



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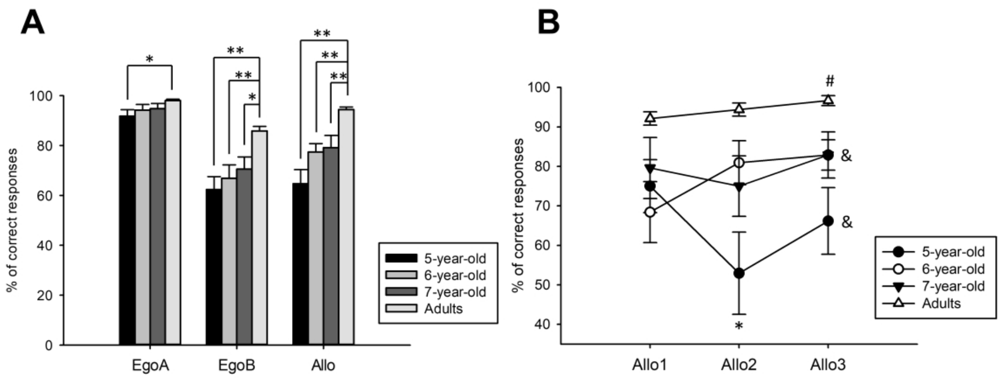

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