Convergence and Divergence in Representational Systems: Emergent Place Learning and Language in Toddlers

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Abstract

Language and spatial reasoning are two primary abstract representational systems in humans. Language acquisition has been much studied, while the ontogeny of spatial navigation is comparatively less well understood, as is the relationship between early language and space. This study explored emergent place learning and language in 16- to 24-month-old children using a spatial task adapted from the Morris water maze, and the MacArthur Communicative Development Inventory. Children were placed in a circular enclosure and a puzzle was hidden under the floor at one location. Before each trial children were disoriented and placed in the maze from a different starting position. Their search strategies and success at finding the puzzle were coded. Older children demonstrated more spatial searching and more goal-finding success, as well as greater overall expressive vocabulary. Place learning and expressive language both significantly correlated with age, but place learning and language did not correlate with each other once age was partialled, with one crucial exception: a theoretically-predicted correlation between prepositions and goal localization.

Keywords: Place learning; spatial language; spatial development

Introduction

People navigate the world every day, utilizing various spatial strategies. There are two systems of such strategies; egocentric (involving self-referencing), and allocentric (using viewer-independent referencing). Allocentric strategies include landmark use (identifying features at or immediately near a goal) and place learning (triangulating a location using relationships between distal features). Evidence suggests that adults use both ego and allocentric strategies dynamically, preferentially weighting each according to the task and context (Iaria, Petrides, Dagher, Pike & Bohbot, 2003), and that there are different neurological underpinnings, with the caudate underlying egocentric strategies and the hippocampus underlying place learning (Compton, 2004; Iaria et al, 2003). However, the way in which they are combined is only beginning to be understood. This is an especially interesting question in young children who begin navigating when both their bodies and minds are changing rapidly, allowing them unprecedented access to new ways of physically and mentally interacting with the world.

A primary goal of this study was to use an adapted Morris water maze to explore the nature of children's search strategies as place learning emerges. Developmentally, egocentric strategies appear first, followed by landmark use (Acredolo & Evans, 1980; Cornell & Heth, 1979). Even in early development young children, like adults, can use a dynamic combination of strategies. For example, 6-month-olds rely on egocentric strategies to look for a previously viewed stimulus after changing perspective 180 degrees, while 9- and 11-month-olds use a mix of ego and allocentric responses. However, when the salience of the target is increased, all age groups shift to using more allocentric strategies (Acredolo & Evans, 1980), suggesting that even as spatial abilities emerge they are dynamically incorporated with other spatial strategies. Significant changes in spatial representation occur at 20-24 months, including the emergence of place learning (Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Sluzenski, Newcombe, & Satlow, 2004). For example, while 18 to 22-month-olds are able to use dead reckoning to search for a hidden object after a position change, only children older than 22 months can use external features to increase the accuracy of their searches (Sluzenski et al., 2004). From this research it is clear that various search strategies come online early, with place learning emerging at about 24 months of age. What is missing in the developmental picture is a research methodology that can provide descriptive data about children's search strategies as place learning comes online, elucidating patterns of variability across individuals and age ranges in early navigation. The Morris water maze is a place learning task that has been used with adults and non-human animals to obtain descriptive data regarding search characteristics across age ranges (Moffat & Resnick, 2002) and under various lesion conditions (Compton, 2004). In the standard water maze, individuals are placed in a circular tank and navigate to a platform placed invisibly under the surface. Each trial begins from a different location, and success requires calculating the location of the platform relative to surrounding features in the room. Adaptation of the water maze for young children allows us to narrow the gap between the animal, adult human and infant literature. Additionally, the adapted maze can provide detailed information about children's performance regardless of their ultimate success in finding the target.

A second goal of this study was to explore the relationship between early emergent space and language. Traditional views hold that language and space can be dissociated to a certain extent. However, there is also reason to believe that language and space may be inter-related, with content dependent linkages that both constrain and enable development. It has been argued that the terms used to code space in one's native language can affect categorization and hence processing of non-linguistic spatial representations (Levinson, Kita, Haun, & Rasch, 2002; but see Li & Gleitman, 2002). Interestingly, children who have Williams Syndrome (who have severe spatial deficits yet relatively strong language) show spatial-specific language deficits, that is, prepositions (Landau & Hoffman, 2005; Phillips, Jarrold, Baddeley, Grant, & Karmiloff-Smith, 2004). Developmentally, the specificity hypothesis (Gopnik & Meltzoff, 1986; 1987) suggests that during the single word acquisition period of language development there is a relationship between the emergence of linguistic content types and related cognitive skills, the idea being that both linguistic and non-linguistic skills rely on similar foundational knowledge and that as they come online they can have a reciprocal effect on each other, influencing mutual development. Thus, it was predicted in this experiment that both place learning and language would show rapid yet independent development, with the exception of prepositions, which were predicted to correlate with place learning.

Experiment

Participants

Participants were 32 children aged 16-24 months (M=20.4 months), 14 boys and 18 girls, approximately equally distributed. Five participants were discarded due to fussiness or failure to continue searching, and five due to technical issues such as camera failure.

Materials

A 10' diameter child's pool with 8" high inflatable sides was covered with a double layer of 15" x 15" tarp-covered foam tiles. The foam underneath four tiles, one per quadrant, was cut away to hide a puzzle containing eight pieces that when correctly fitted made a sound (only one location was used per participant). With the puzzle in place the goal was visibly indistinguishable. The pool was placed in a rectangular room with many features including the door and other experimental apparatuses.

Expressive language was measured using the MacArthur Communicative Development Inventory (MCDI) short form for toddlers (ages 16-36 months). This is a checklist that a parent fills out by noting which of list of nouns (100), verbs (103), and prepositions (26) a child spontaneously says.

Procedures

Children and their parents entered a waiting area to complete consent forms and the MCDI. Subsequently they entered a different room for the place learning experiment.

Familiarization The purpose of familiarization was to introduce children to the task and to give them experience finding the puzzle in its specific location. The puzzle was placed on top of the goal tile. Children and the experimenter entered the pool and played with the puzzle. Next, the experimenter demonstrated hiding the puzzle, then lifting the tile to find it, and encouraged children to try. Familiarization ended when children had demonstrated that they understood that the goal was to find the hidden puzzle by independently lifting the tile and placing a piece at least twice.

Testing Testing consisted of four learning trials, (with the puzzle hidden), one probe trial, (with the puzzle removed), and one control trial (with the puzzle clearly visible on top of the tile) to ensure that children were still motivated. On each trial the experimenter took the child and, while the parent walked to a different quadrant, spun the child to disorient her. This combination of disorienting children while the parent moved and beginning each trial from a different location ensured that children could not use dead-reckoning to find the puzzle, but instead had to rely on true spatial navigation. The parent took the child and set her down inside the pool facing outwards with a puzzle piece, to search for the puzzle. Children searched, by lifting tiles, for 60 seconds, or until they found the puzzle. After each search the experimenter replaced the tile, and children were allowed to search any tile as many times as they liked in a trial. If children did not find it, the experimenter showed the puzzle briefly, so that children could approach, lift the tile, and place the piece. Note that every trial ended with the child finding the hidden puzzle, with or without a cue, and only data was included from children who completed every trial this way. This served as a control to ensure that children understood the task and were still motivated to find the puzzle. After children found the puzzle, parents walked back around the pool to lift their child out while the experimenter re-hid the puzzle. Then the experimenter took the child back to the pool's center to start the next trial. Some children did not tolerate being held by the experimenter, in which case the parent spun the child while the experimenter walked to the starting point. The parent and experimenter then exchanged places, and the parent placed the child in the pool. Additionally, some children required their parent to step just over the side of the pool during the trial.

Data Coding

Expressive Language The number of nouns, verbs, and prepositions was tallied, and summed for a total vocabulary score.

Place Learning Place learning was measured by whether a child correctly located and lifted up the target square, to reveal the puzzle hidden underneath (maximum once per trial). A place learning (PL) score score was calculated for each child by adding the number of times the child found the puzzle and dividing by 5 (total number of trials).

Search Types To further explore spatial development, the relationship between age, place learning, and search characteristics was explored. Data on search types from the first four learning trials was used, since on the probe trial failure to find the puzzle in its expected location may have resulted in children differentially interpreting what was expected of them. A modified place learning (mPL) score was calculated using the number of times children located the goal divided by 4 (number of learning trials). Children varied widely in walking speed, and often stopped and started intermittently during a trial. Because of this inconsistency, time measures were not utilized. Instead, children's discrete search choices (indicated by lifting a tile) were categorized. Each trial consisted of potentially multiple discrete searches as children lifted tiles before finding the target square. Each search before finding the target in every trial was coded as one of five types, in two general categories, spatial and non-spatial. Spatial types were peripheral (searching under a tile approximately the same distance from the perimeter of the pool as the goal), or adjacent (searching under a tile immediately adjacent to the goal). Non-spatial searches were social (lifting the tile under another person), egocentric (lifting the tile under self) or unrelated (a non-spatial search that was neither under the child nor someone else). (See figure 1).

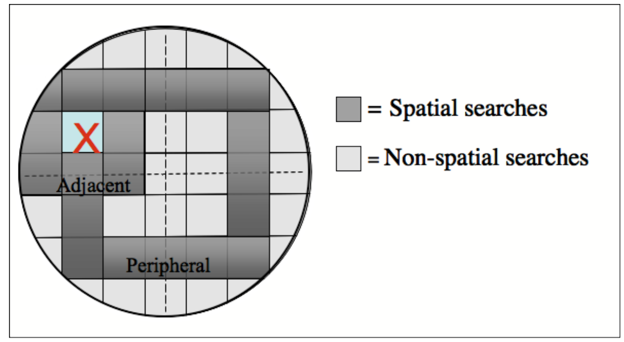

Figure 1: Schematic of spatial and non-spatial search divisions, with "x" marking the goal.

Although search types were exclusive within category (e.g. a search next to the goal was coded as adjacent not peripheral), a choice could be double-coded across categories, (for example a search could be both spatial adjacent and non-spatial egocentric.) Scores were summed for each type across all four learning trials and converted into percentages by dividing by the total number of searches.

Results

Place learning and age

A primary question was whether older children were significantly better at place learning than younger. Participants were divided at the median into two age groups, 16- to 19 month-olds, (M=17.6, SD=1.3) and 20- to 24-month-olds (M=23.0, SD=1.4. A one-way Anova (age) revealed a significant effect of age on place learning (F (31)= 10.484, p=.003), and % non-spatial searching (F(31) = 11.27, p=.002) and a marginal effect of age on % spatial searching (F(31)=3.82, p=.06). (See figure 2).

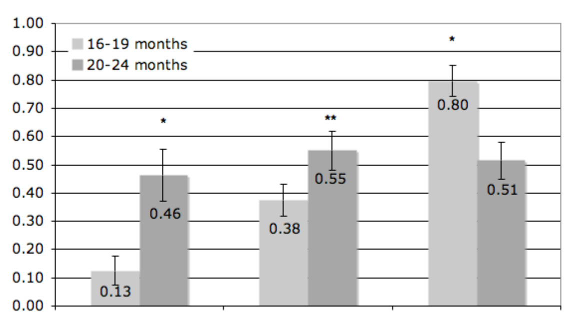

Figure 2: Proportion place learning, spatial, and non-spatial search types with age. Note *p<.05, **p=.06

To explore search types across development more closely, to determine if children showed similar gains across time, an Anova was done using smaller age divisions. The resulting groups were 16-month-olds, (M=16.27, N=6), 17-to 18-month-olds (M=17.27, N=6), 19- to 20-month-olds (M=19.64, N=6), 21- to 22-month-olds (M=22.35, N=5), and 23- to 24-month-olds (M=23.96, N=9.) Despite small subject sizes, a one-way Anova (age) revealed a significant effect of age on place learning, % spatial searching and % non-spatial searching. Percentage of non-spatial searches showed a significant linear decrease (F(1,4)=12.94, p=.001) with age. The % spatial searching showed both a linear increase (F(1,)=8.56, p=.005) and quadratic increase (F(1,4)=3.04, p=.05) as a function of age, reflecting an initial rapid increase in spatial searching between the 16 month and 17- to 18-month-old age groups within an overall linear trend (See figure 3).

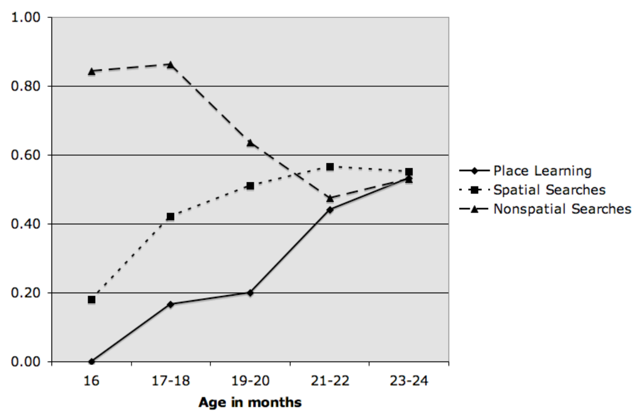

Figure 3: Proportion place learning, spatial and non-spatial search types by one and two-month age groups

These results suggest that with age children show a decrease in non-spatial strategies and an increase in spatial strategies and place learning. Interestingly, the shift in spatial strategies at about 17-months precedes actual goal finding, since it is not until about 20 months of age that children were able to reliably find the puzzle on multiple trials.

Age, Place learning, and Language

Correlational analyses were conducted to explore the relationship between age, spatial development and language, with total number of searches partialled out to ensure that older children did not experience greater success simply from lifting more tiles. There was a significant relationship between age, goal finding, spatial searching and language with a negative relationship between age and non-spatial searching (see Table 1). Although place learning and language were correlated, (r(29)=.59, p<.01) when age was partialled out the correlation dropped to non-significance (r(28)=-.15, p=.44, suggesting that both place learning and language undergo rapid parallel, yet independent, development. Although even 24-month-olds have not yet achieved adult-like proficiency in either place learning or language, there is a clearly rapid acquisition in both domains over a very short developmental time period.

To further explore this relationship, goal finding, spatial search types, and language subtypes were correlated, partialling out age and total number of searches. There was a significant relationship between spatial searches and place learning, and a negative relationship between non-spatial searches and place learning (see table 2).

Table 1: Correlations between age, place learning, search type and language, partialling out total number of searches

Measure	Age	Place Learning	Spatial Searches	Non-Spatial Searches
Age				
Place Learning (PL)	.60**			
Spatial Searches	.46**	.63**		
Non-Spatial Searches	-.60**	-.69**	-.81**	
Total Language	.72**	.51**	.23	-.40*

Note *p <0.05, ** p<0.01

Table 2: Correlations between spatial and language measures partialling out age and total number of searches

Measure	Spatial Searches	Non spatial searches	# Nouns	# Verbs	# Prepositions	Total Language
Spatial Searches						
Non spatial searches	-.76**					
# Nouns	-.06	.03				
# Verbs	-.23	.09	.82**			
# Prepositions	-.05	-.00	.67**	.79**		
Total Language	-.15	.06	.94**	.96**	.81**	
Place Learning (mPL)	.46*	-.47*	.18	.09	.36*	-.15

Note * p<.05, **p<.01

Only adjacent searches correlated with goal finding (r(27)=.38, p=.04), while peripheral and equivalent searches did not, supporting the idea the idea that goal finding relied on using distal cues to narrow searches to the correct area of the pool. The lack of relationship between place learning and language subtypes was of particular interest, especially given the lack of relationship between place learning and total language. As predicted, place learning significantly correlated with prepositions, but not with any other language subtype, supporting the idea that place learning and spatial language bear a unique developmental relationship to each other.

Discussion

In this study, 16- to 24-month-old children's place learning skills were tested on an adapted Morris water maze, to explore the emergent nature of place learning and the relationship to expressive language development as measured on MCDI. Previous research has suggested that children undergo a rapid change in spatial representation skills at approximately 20 months of age, a finding that was verified in our current study. Interestingly, place learning itself, that is, the ability to find the goal, was preceded by a drop in of use non-spatial search strategies and an increase in use of spatial. Children as young as 17 months showed a sharp increase in spatial strategy use compared to 16-month-olds. Remarkably, this shift did not initially result in goal finding and hence reflects a change that arises early and persists unrewarded before it becomes effective. Most models of learning, like reinforcement learning, rely on some type of feedback (Sutton & Barto, 1990). The exception, associative learning, is characteristic of the hippocampus (McNaughton, 1993). Therefore it remains an intriguing question whether the shift results from endogenous neurological changes including early hippocampal maturation, or rather external factors not measured here. In fact, it is likely the spatial changes are due to a number of converging factors including brain maturation, experience-dependent behavioral changes, and other cognitive development. For example, older children can and do navigate more independently than younger children, as do more securely attached vs. less securely attached children, which can affect their understanding of space (Hazen & Durrett, 1982; Clearfield, 2004). In fact, the wide variability observed within the same age groups (for example some 24-month-olds never found the goal, and one 17-month-old found it three times) provides intriguing evidence that the developmental process may be impacted by multiple factors, and this picture is only beginning to be understood.

Language and place learning showed significant yet non-correlated development occurring from 16- to 24 months. The exception was prepositions, the acquisition of which was correlated with place learning. Often language and spatial representation are considered to be largely dissociable systems, yet evidence exists to suggest that there are key areas of overlap. Given the methods utilized here it is not possible to know the directionality of this relationship, if indeed there is a clear uni-directional relationship rather than a mutual interactive one. Interestingly, all but one of the children who used prepositions also found the goal at least once, but many of the children who found the goal had no prepositions, suggesting that if the relationship is directional it is that spatial understanding influences spatial language. Future studies incorporating more direct language measures are needed to further explore this question. At minimum, the correlation between prepositions and place learning suggests that representations that rely on understanding spatial relationships between objects emerge in two very different cognitive systems behaviorally (as evidenced in successful goal searches) and linguistically (as evidenced in prepositions) on a developmentally related timescale. The finding here, of a spatial specific language linkage, presents an intriguing story about the interaction between various cognitive systems, beginning early in development, in fact, as early as either place learning and expressive language can be measured.

Future Directions

The findings from this study reveal complex early language and spatial systems in toddlers. Although it is clear that by 24-months of age toddlers are able to somewhat use place learning to find a hidden goal location, it is not clear how they are able to access and weight information in the environment and integrate it with other spatial and egocentric information for efficient way-finding. Therefore, further work needs to be done to examine how children variably weight different information sources throughout development as their place learning skills become more mature and reliable. In addition, further work needs to be done to more closely explore the spatial and language relationship found here, incorporating direct language measures rather than relying on parental report tools, like the MCDI. Finally, longitudinal studies need to be conducted to explore the stability of individual differences in a variety of linguistic and spatial paradigms across development

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