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Spatial Memory in Intellectual Disability: Explanation with the Parallel Map Theory

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Abstract **Review Article**

The parallel map theory explains that the hippocampus encodes space with two mapping systems: The bearing map created from "*directional cues and stimulus gradients*"; The sketch map constructed from "*positional cues*". The integrated map combines the two mapping systems. Such parallel functioning may explain paradoxes of spatial learning in intellectual disabilities. This people may be able to memorize their surroundings in a highly detailed way, thus ordering their sensory perceptions into a representation that includes the precise localization of static objects, they are not able to "*map*" their own spatial relationship to those objects. The detection of moving objects by these same subjects contributes to a primary bearing map. The primary map is thus generated by relying on this kind of static map, but also by detecting moving objects. This process can be described as a spatial mode of processing separate objects within the structure of an absolute reference system.

Keywords: Parallel map theory; intellectual disability; spatial memory.

INTRODUCTION

The cognitive map theory developed by John O'Keefe and Lynn Nadel in 1978 [1] has been the most influential [2, 3]. But another theory articulated by Lucia Jacobs and Françoise Schenk is very pertinent because it explains that: "*the hippocampus encodes space with 2 mapping systems. The bearing map is constructed primarily in the dentate gyrus from directional cues such as stimulus gradients. The sketch map is constructed within the hippocampus proper from positional cues. The integrated map emerges when data from the bearing and sketch maps are combined*".

Ontogenetics tells us that visually constructed cognitive maps cannot be reduced to physiological processes alone, because vision is based upon both biology and culture. Alain Berthoz [4] asserts that: "*It is the first interaction with the world. Before walking with legs, we walk with eyes,";* a process which Andrew Meltzoff, in his findings on early imitation behavior, reveals to both require and stimulate developmental plasticity Berthoz called this "simplexity" [5], i.e., a compilation of simple rules organizing complexity in living organisms. Human cognition mediates this process in such a way that "despite the complexity of natural processes, the brain can prepare an action and anticipate its consequences". Although requiring a detour and its subsequent cost, this functioning facilitates coherence and continuity.

To put it simply, large specialized modules co-operate to mediate the integration of visual information in order to support action. The modules are: the gaze system, the motor system, and the visual system. All three are supervised by the schema control system. Simplexity rules then integrate this diversity by adaptively combining several feedback loops.

Various types of intellectual disabilities (ID) involve distinctive or abnormal features of visual exploration strategies. These features can be subsequent to neurological deficits in the organization of actions or intentions, or they may be related to cognitive deficits experienced as visual exploratory strategies are developed and/or acquired. Looking at the effect of a handicap on visual signal integration and subsequent strategies for information collection can illuminate certain aspects of cognitive deficits which a comprehensive approach may overlook. Furthermore, as several authors [6-8] have "*clearly expressed, one should insist on the importance of understanding the underlying processes in order to maximize individual performance*". For these authors, "*analyzing basic* *visual cognitive processes is fundamental in order to offer effective interventions*".

Spatial Orientation and Detection Processes

The parallel theory by Jacobs and Schenk [8] is very interesting because: "*it puts in parallel using internal and external cues to relate its current position to its start point in the environment. Internal cues such as self-generated movement cues inform the navigator how far and in which direction it has moved from a given position. External cues such as landmarks can be used in two different ways, both for direction and for position. Locomotion generates a dynamic sensory flow in diverse modalities (proprioceptive, tactile, auditory, olfactory, and visual). The navigator integrates some or all of this information to update the current position relative to the start point. Path integration is the outcome of the process that regularly updates a directional vector. The vector is generated by the navigator's movement during an exploratory bout and is based on this dynamic sensory flow and the efferent copy of the intended action. The path integration vector encodes the distance and direction from the start point of exploration, where the vector is apparently reset. Thus, path integration allows the navigator to beeline to its most recent start position at any time*".

Sensory-motor activities facilitate body control within its environment as a function of the targets determined by the individual. Behavioral adaptations include postural control as well as following external objects with the eyes and the hand. This type of behavior was compared to that of a controller [9]. As highlighted by Markkula *et al*., [10] this theory is still used to develop mathematical models of human behavior.

This basic model contributed to the theory of perceptual control [11], the study of sensory information [12-15]. Eventually, it led to the development of a certain number of notions of ecological psychology [16]. These theories made it possible to determine the perceptual invariants which supply direct sensory access to processed data.

Optimal control models of sensory-motor behavior suggest that subjects' actions aim at minimizing cost, generally combining errors and control efforts [17]. Theoretical predictions of these models were confirmed through experiments [18] and resulted in the creation of machines which reproduce human movement [19, 20].

The movement can begin when the sensory-motor state is considered highly reliable. Toward the end of the movement the state depends on sensory-motor integration. This mode of data integration facilitates a comparison between the planning stage of the movement and the efference copy of the accomplished movement. The difference between the two images (the planning image and the copy image) is used for corrections until an optimal balance is achieved [21]. Land and Furneaux [22] highlight that the gaze necessarily precedes the action because the goal of vision is to provide the motor system with the data necessary for action. All actions follow the same pattern: the gaze identifies the necessary data, localizes a target, and guides the hand or the body. The object is then seized, or the task is carried out. The efference copy belongs to the bearing map, which functions as the permanent frame or scaffold for the integrated map. Jacobs and Schenk [8] assert that the bearing map is both consolidated and stored in the dentate girus. Additional spatial exploration means that the map grows larger and becomes more complex, but this also means there must be a way, an inherent mechanism, in order to integrate additional information. In an ID context, there seems to be a decrease in the addition of more information.

For Jacobs & Schenk [8]: "*in addition, if the bearing map is a permanent reference system, in contrast to the ephemeral sketch map, which should rapidly acquire new data, overwriting the old. For the hippocampus, the spatial environment that is experienced by a navigator changes throughout life. Incorporating new spatial data in the bearing map thus may require the addition of new structural elements to increase storage and computational capacity*".

Jakobs & Schenk [8] suggest there is: "*an important distinction between pure path integration and the reliance of the hippocampus on path integration. Path integration itself (a single, one dimensional gradient produced from vestibular and external sensory feedback) is simply a vector that is exported to the hippocampus, which then assigns meaning to this vector. In this case, path integration would not be a property of the hippocampus but a process whose output is used by the hippocampus in constructing one-dimensional (1-D) and two-dimensional (2-D) maps. The vector obtained from path integration could be a primitive working memory representation, one that is reset at the start of every exploratory bout. It might then acquire more dimensions when it is associated with external points, such as an identifiable start position This association of the working memory vector with external landmarks would lead to a richer representation of space, one that cannot be computed without the path integration process. The properties of such a representation would exceed those provided by pure path integration*".

These details of the cue environment are important to help specify visual perception in intellectual disability.

Specificity of visual perception in intellectual disability

Atypical gaze is often observed in the context of psychiatric disorders, for example in schizophrenia or autism [23, 24]. Social signals are often mediated by gaze, and altered gaze control might also be connected to disruptions in social or cognitive processes.

Directional Landmarks and Gradient Cues for Constructing a Bearing Map

Directional Landmarks

Jakobs & Schenk [8] specify that directional cues polarize the navigator's environment rather than identify a specific position in space : "*this may be a directional landmark (for example a mountain range) or gradients of distributed cues (e.g., odor, sound, polarized light, magnetic fields)*". A directional cue may be static or dynamic; it depends on whether the navigator is moving or not. A directional cue generally does not change with small movements of the navigator [25].

Stimulus Gradients

Switching to simple gradient maps involves the distributed cues (for example odor, sound, polarized light, magnetic fields). The navigator: "*must move up and down the gradient to construct its crude representation of space with repeated sampling and by knowing its rate of movement. He must precisely calibrate changes in the single perceptual dimension (i.e., the polarity of sensory input, whether increasing or decreasing) to its own rate of movement. Once a navigator can do this, it can predict the sensory input that it will experience at a future location*". This means that as the navigator negotiates the gradient, it creates a 1-D map, in the words of Neisser [26]. The gradient indicates knowledge of its own movements, and the navigator relies, then, upon the gradient map in combination with knowledge of time spent traveling to calculate distance.

However, if the sampling rate or rate or rate of movement becomes muddied, it means that the map becomes unreliable and at that point it becomes difficult for the navigator to self-correct.

It is generally accepted that individuals with autism have "non-habitual" perceptive processing associated with an enhanced visual discrimination [27, 28]. Following upon this are further studies [29] which, in general, exposed certain abnormalities in terms of how typically non-social stimuli are perceived. Yet the perceptive processing in ecologically relevant tasks has not yet been studied in the specific population of individuals with intellectual disabilities.

The studies following people with ID are a problem because spatial tasks are conducted in virtual reality or with neuropsychological tests and their ethological validity has been questioned [3, 30, 31]. When moving out of theory and into real life, it's clear that a variety of sensory modalities (visual, vestibular, and proprioceptive) offer relevant data that contribute to and integrate the cognitive map.

Positional landmarks for constructing a sketch map

Positional Landmarks

Positional landmarks work differently than directional landmarks; they infer position with respect to relative distances and object position. Here, the cue's appearance changes quickly when the navigator moves, thus enabling the navigator to figure out the distance required to negotiate between landmarks (or between a landmark and the navigator) [32, 33]. Positional landmarks are unique objects because they can be processed separately. When a situation involves multiple situation clues, each can be processed based on its relation to at least one other cue. Jacobs and Schenk [8] confirm that: "*this relationship forms the basis of relational coding. When different objects form a symmetrical geometrical figure, the figure is identifiable even if the identity of each component object is not learned. This creates ambiguity among symmetrical positions in a configuration, even when each corner is uniquely identified by local cues*".

People with ID, however, focus and memorize a single directional cue as part of a symmetrically shaped array as well as when a new directional cue appears somewhere in the margins of the original area [32].

This suggests that ID individuals process directional information when it is integrated in a geometrical figure, or by identifying unique objects – but cannot do both. Concretely, the information taken from a landmark is highly dependent on both the observer and the context. There is also the implication that direction and position are processed independently within the context.

Giuliani *et al.*, [32] conducted a study with individuals having mild to moderate ID to see whether the eye movements made during their visual exploration of salient objects might be related to the detection of spatial changes in the arrangement of those objects. Through an analysis of both gaze frequency and declarations of noted changes to the object, these researchers reported that ID individuals were more likely to detect object changes compared to the control group, but were within the control range when a new object was added. Interestingly, the ID group did not notice an object's disappearance but did detect a change of position. The correlations between the detection of change and the frequency with which gaze was reoriented suggested that, compared to the control group, individuals with ID were more affected by object salience. This suggests that ID subjects have enhanced attention to the permutation and that differentiating between salience and novelty is a possible path to understanding the ways in which this particular population adapts/reacts to a novel situation. This case indicates that gazes focused on the largest objects might provide some affordance in the sense of ensuring the object's attention and with that, a memory of its position.

At the same time, sketch maps must be housed within unique locations somewhere on the bearing map. When the situation involves centrally-placed objects—meaning that directional references are missing—the navigator loses control without these cues. This means that ID individuals are unable to connect the objects (i.e. the sketch map which connects the objects to one another) with a stable bearing map. Additionally, sketch maps are not consolidated but created again and again in new versions, which is an explanation for the low tolerance of cue rotation [7, 33].

Alternatively, ID individuals may connect their sketch map to a far-removed object as a beacon for directional data. When this happens, if the configuration is rotated the place fields become disorganized because the ID navigator expects landmarks to maintain a certain relationship to the external world. This means that ID individuals are impaired in terms of uniting new sketch maps with the consolidated bearing map.

By constructing a model from the simplest units of navigation, orientation to 1-D maps from distributed stimuli, this inevitably leads us to conclude that the hippocampus certainly encodes and integrates parallel mental representations of the external environment.

In summary, the use of directional landmarks, positional landmarks, and gradient cues induces the predictability vs reactivity dualism [34, 35], meaning that a relational and more abstract representation is what guides perception (predictability), further emphasizing the whole configuration instead of its parts and looking toward an overall aspect rather than a list of details. Oppositely, the level of reactivity would be a reply to the salience of a local change, i.e., an affordance [36]. Finally, personal, social and emotional biases influence perceptual salience, and this must be recognized in order to ensure that salience is adequately considered.

Predictions of the Parallel Map Model for intellectual disability

Table-1: Predictions of the parallel map theory for ID. The four patterns of spatial performance result from the presence or absence of the parallel maps. The residual learning, resulting from the loss of a single map (bearing or sketch), allows the navigator to find his way, using transects when the bearing map is intact and local loops when the sketch map is intact

People with intellectual disabilities		**SKETCH MAP**	
		INTACT	**IMPAIRED**
BEARING MAP	INTACT	The navigator finds his way and chooses a direct path	The navigator finds his way because he knows the direction but not the distance. The navigation is organized into long transects across the way
	IMPAIRED	The navigator finds his way using local loops because he knows the construction from the arrangement of positional cues but he is unable to organize search from new release point.	The navigator doesn't find his way

Table-1 Predictions of the parallel map theory for ID. The four patterns of spatial performance result from the presence or absence of the parallel maps. The residual learning, resulting from the loss of a single map (bearing or sketch), allows the navigator to find his way, using transects when the bearing map is intact and local loops when the sketch map is intact.

These studies indicate that ID individuals have specific capacities when processing visual data [37, 38] related to the subject's focus on parts and details [39]. Other authors [40] assert that "*autistic perception is autonomous from higher-level, top-down influences and may involve a one-to-one or veridical mapping process. On this account, hypersensitivity in autism results from an imbalance in inhibitory and excitatory connectivity between local neural networks in sensory regions*" [27, 41-44]. There is a risk that this mention of an "autonomy from higher-level influences" might lead to the mistaken idea that ID individuals lack higher level processing, which, in turn, may prevent clinicians and others from understanding what are actually sophisticated adaptive compensatory strategies. Furthermore, although there have been many (important) studies related to autism and other intellectual disabilities, most of the work done to understand these patients' impairments has focused on investigating their visual exploration of social stimuli on pictures [45-47] and not on the ways in which ID inviduals explore and interact with their environment.

To encourage the understanding of adaptive strategies and motivations as well as provide guidelines for remediation methods, what's needed is a more thorough examination of the visual exploration of ID individuals. Some recent works are concerned with gaze abnormalities in autism, but these are mainly looking for specific stimuli [48] or are considering attention impairment in a general way [49]. Some authors endorse studies based on eye-tracking to obtain valuable data « on what elements attract the individual's attention (and which ones do not), for how long, and in what sequence », but there are, as yet, not systematic enough [6].

The hypotheses outlined here come directly from my clinical experience. It has shown me that ID individuals do not filter incoming data which means they are constantly overwhelmed by this excess of information that is not aggregated into "superobjects", whether spatial (Giuliani & al, 2011), or symbolically abstract entities. For day-to-day experiences, I advise those who take care of these persons to reduce the amount of given information. I also teach ID individuals to seek and create calm and understimulating environments in order to help themselves integrate collected information. Because this population is over-reactive and susceptible to basic visual affordances, I use cognitive behavioral methods to give them the means to control their environments. I also give assistance in the form of therapy to help them develop more suitable ways of perceiving their environment. From this description, I develop simple and intuitive stratagems to encourage more suitable - but still spontaneous - visual guidance for reeducation. This might include the suggestion that the therapist wear a colored ribbon, or leaves their hair down, or deposits a salient object in a particular position. Eye-tracking technology is a simple way to assess how much the subject relies on these cues. It becomes difficult to explain this process in a rigorously scientific manner because it is based on the individual particularities of each patient, their spontaneous biases (the way in which they explore their surroundings), and the environment they are used to – however, this is all integrated into a theoretical perspective of brain function.

CONCLUDING HYPOTHESES

The Bearing Map is constructed from the integration of self-movement cues (egocentric) with stimulus gradients and directional cues. The navigator only needs to adjust self-motion cues and change the intensity of a distributed cue when deciphering its next position in the coordinate system. The sketch map is constructed from an arrangement of positional cues. These separate local landmarks work together as a topographic map. This means that the sketch map is a finely detailed mental representation appropriate for local navigation. The positional codes within sketch maps are allocentric, as each cue refers to another component of the sketch map.

The specificities of these persons in integrating visual information emphasize two complementary issues when adapting therapeutic approaches meant to improve quality of life**.** First, ID individuals memorize their environment in a highly detailed way so that they can assimilate perceptive data into a representation of the precise location of static objects, but not their spatial relation to nearby objects. This means that this spatial map does not involve "superobjects" or sketches that work from a simultaneous grouping of objects perceived as close together. Second, more than just a reliance on this kind of static "patchy" map, I suggest that this population detect moving objects (or of static objects during exploratory phases) in order to create a primary bearing map. This is a spatial mode of processing separate objects within a framework of an absolute reference system, similar to the bearing map in the dual mapping process developed by Jacobs and Schenk [8]. According to this model, a hypothetical "patchy" map would direct and influence movements, just as a bearing map does, with the load that it does not offer "a light and abstract" cognitive map of related places. When not integrated to a sketch map, the result is a possible overflow of active spatial information.

In sum, I think that the bearing map is intact but the amount of information to be added is limited in terms of incorporating new spatial data. Under the experience, this may require the addition of new structural elements to increase storage and computational capacity. These structural elements may be reduced for this population. Individuals with ID can use the bearing map in a known environment because the navigator can use familiar directional cues and stimulus gradients. People with ID use the sketch map in new environments because the sketch map uses the positional cues. They may be stored elsewhere than the hippocampus as spatial objects, and are possibly chunked to one another. Instead, ID individuals may make a chain of sketch maps and with this create a route. Our view is that route creation is radically different then the systematic repetition of the same trajectory involved in simple route learning. My clinical experience shows me that the individual with ID is seeking routine in his motion. The ID navigator is impaired in terms of the integrated map when data from the bearing and sketch maps are combined. This impairment may be caused by neurological deficits [50] occurring as actions or intentions are organized or because of disabilities related to cognitive deficits experienced as visual exploratory strategies are constructed and acquired [7].

Conflict of Interest: The author does not report any conflicts of interest.

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