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Review article

Vision, spatial cognition and intellectual disability

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ABSTRACT

Vision is the most synthetic sensory channel and it provides specific information about the relative position of distant landmarks during visual exploration. In this paper we propose that visual exploration, as assessed by the recording of eye movements, offers an original method to analyze spatial cognition and to reveal alternative adaptation strategies in people with intellectual disabilities (ID). Our general assumption is that eye movement exploration may simultaneously reveal whether, why, and how, compensatory strategies point to specific difficulties related to neurological symptoms. An understanding of these strategies will also help in the development of optimal rehabilitation procedures.

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1. Introduction

The adaptation of vision as a tool for writing and reading is a recent cultural development, as discussed by Land (2009). During the early stages of primate evolution, the basic role of vision was to provide fundamental information needed for adaptations of vital importance such as hunting, food gathering and shelter building. More generally, vision plays a prominent role in the exploration contributing to spatial cognition, even in nocturnal rodents such as laboratory rats (Schenk, 1995). In rodents, the neurological basis of spatial representations has been approached from the recording of hippocampal unit activity (see for example, Poucet, 1993), which are closely related to body localization and orientation.

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A predominance of vision over olfaction for spatial orientation in a macrosmatic and nocturnal species (Lavenex & Schenk, 1996) emphasizes the advantage provided by a sensory modality that enables the localization of distant landmarks, whereas olfactory information must be combined with locomotion to inform about actualized position. In monkeys, these units are clearly related to where subjects are looking at in their environment (Rolls, 1999). Hence, primate eye movements may shed some light on the brain's cognitive mechanisms in a broad sense, since gaze control is directly related to anticipatory processes and executive functions.

From an ontogenetic perspective, vision cannot be approached as a mere physiological process because it is a combined product of biology and culture. As highlighted by Alain (, p. 252): "It is the child's first interaction with the world. Before walking with his legs, he walks with his eyes." This interaction requires and stimulates developmental plasticity, as revealed by the early imitation behavior reported by Andrew Meltzoff. This means that we are faced with what Berthoz called "simplexity" (2009), i.e., an assembly of simple rules organizing complexity in living organisms. This assembly is functionally mediated in such a way that "despite the complexity of natural processes, the brain can prepare an action and anticipate its consequences". For Berthoz (2009, p. 12), these processes contribute to a sense of coherence and continuity, even at the cost of a detour.

Essentially, the integration of visual information to support action is mediated by a cooperation among large specialized modules: the gaze system, the motor system and the visual system, all three under the control of a schema control system (Land, 2009). This diversity is integrated by simplexity rules that unite numerous feedback loops in an adaptive style. The emergent style can be assessed using eye movement recording.

Various categories of intellectual disabilities (ID) are associated with distinctive or abnormal features of visual exploration strategies. These might be a direct consequence of neurological deficits in the organization of actions or intentions. Disabilities might also be secondary to cognitive deficits during the development and acquisition of visual exploratory strategies. Understanding how a handicap might modify visual signal integration and subsequent strategies for collecting information should shed some light on cognitive deficits otherwise inaccessible to a comprehensive approach. Essentially, eye tracking is currently used in a variety of research to investigate visual and cognitive processing in individuals with ID (e.g. individuals with autism spectrum disorders, Down Syndrome, intellectual/developmental disabilities of unknown origin, William's Syndrome, Rett's syndrome, and Fragile X syndrome, Hanley, Riby, Caswell, Rooney, & Back, 2013; Owen, Baumgartner, & Rivera, 2013; Riby & Hancock, 2009; Wilkinson & Light, 2014). Furthermore, as Light and McNaughton (2014), 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.

First, we will revisit the process of spatial learning and detection, and then we will develop its relation to eye movements. Finally, we will consider the specificity of visual perception deficits in ID people. This is not to say that we propose a static diagnostic based on specific eye movement impairment, such as would be obtained from a single biomarker or some endophenotype. Rather, we think that eye movement strategies used by ID people in real life situations might reveal specific dimensions in altered behavioral and coincident cognitive adaptations. In this sense, "abnormal" eye movements do reveal a high cost strategy contributing to the burden of the mental handicap. A re-educative therapy aimed at reorienting this compensatory strategy should reduce the handicap, or, at least, its nuisance. Since eye movements are under cognitive supervision, one can expect that the reorganization of such "motor strategies" would in turn improve cognitive activity, or at least reduce its load.

2. Spatial orientation and detection processes

By definition, habituation is the decrease in responsiveness to a repeated stimulus. Classically, it is considered to be the simplest and most primitive form of learning, common to all living beings (Chapouthier, 1988; Chapouthier, 1999). The response triggered by a stimulus is a combined function of its contrast, i.e. its intensity relative to the current background, and also its contrast with known or familiar stimuli (Berlyne, 1960). This second dimension addresses the question of memory. To relate the observed reaction to higher cognitive processes, one should first discriminate between noticeability and novelty, as proposed by O'Keefe and Nadel (1978). *Noticeability* proceeds from the contrast between a stimulus (sound, light, object, etc.) and any memory representation of it. It can thus be regarded as a basic cognitive process. Moreover, as any stimulus is necessarily associated with its context, whether spatially or emotionally defined, its *novelty* refers to the lack of memory for this particular association (the new position of a piece of furniture in one's kitchen, an odor in a given context), even though both the specific item and its context are already familiar. Naturally, novelty and noticeability are interactive dimensions, since the novelty of an object in a familiar place contributes to the sensory salience of this object via the orientation reaction and its neural basis.

Context can be a particular circumstance. It can also be "a position in space," a place. Spatial representations require memory as an essential feature, and hippocampus-dependent spatial memory is commonly considered to be a phylogenetic precursor of human episodic memory (Burgess, Maguire, & O'Keefe, 2002). Spatial orientation is the basic process that allows subjects to code and remember the relative position of different places in an environment. Its higher cognitive dimension is accounted for by the fact that a "cognitive map" enables new decisions such as short cuts and detours (Tolman, 1948). In this sense, spatial orientation may reveal high order cognitive processes. To quote Neisser (1976), however, such maps are "...not pictures in the head, but plans for obtaining information from potential environments". This knowledge is expressed by eye