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Review

Contextual learning and context effects during infancy: 30 years of controversial research revisited☆

D.A. Revillo, E. Cotella, M.G. Paglini, C. Arias *

Instituto de Investigación Médica M. y M. Ferreyra, IMMF-INIMEC-CONICET-UNC, Friuli, 2434 Córdoba, Argentina

HIGHLIGHTS

- This article reviews 30 years of research on contextual learning during infancy.
- The results show substantial evidence of contextual learning during infancy.
- In some cases context-effects were greater in infants than in adults.
- Procedural factors favoring contextual learning during infancy are examined.
- The results are discussed in terms of the neuromaturational and ecological models.

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ABSTRACT

Over the last 30 years a considerable number of reports have explored learning about context during infancy in both humans and rats. This research was stimulated by two different theoretical frameworks. The first, known as the neuromaturational model, postulates that learning and behavior are context-independent during early ontogeny, a hypothesis based on the idea that contextual learning is dependent on the hippocampal function, and that this brain structure does not reach full maturity until late in infancy. The second theoretical framework views infants not as immature organisms, but rather as perfectly matured ones, given that their behavioral and cognitive capacities allow them to adapt appropriately to the demands of their specific environment in accordance with their maturational level. This model predicts significant ontogenetic variations in learning and memory due to developmental differences in what is perceived and attended to during learning episodes, which can result in ontogenetic differences in contextual learning depending on the specific demands of the task. The present manuscript reviews those studies that have examined potential developmental differences in contextual learning and context effects in rats. The reviewed results show that, during infancy, context can exert a similar influence over learning and memory as that described for the adult rat. Moreover, in some cases, contextual learning and context effects were greater in infants than in adults. In contrast, under other experimental conditions, no evidence of contextual learning or context effects was observed. We analyzed the procedural factors of these studies with the aim of detecting those that favor or impede contextual learning during infancy, and we discussed whether existing empirical evidence supports the claim that the functionality of the hippocampus is a limiting factor for this type of learning during infancy. Finally, conclusions from human research into contextual learning capacities during infancy were also examined. In view of the wealth of evidence showing contextual learning and context effects during infancy, we suggest that future research aimed at exploring the involvement of the hippocampus in this type of learning should be conducted using parameters which allow the expression of contextual learning during each ontogenetic period.

☆ This paper is dedicated to Professor Norman E. Spear and to the memory of Professor Carolyn Rovee-Collier for their invaluable contributions to the field of developmental psychobiology.

* Corresponding author.
E-mail address: carlosargr@gmail.com (C. Arias).

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Contents

1. Introduction

The ontogenetic study of learning and memory has been and continues to be a major issue for psychology. Several general theories have been proposed to guide research on this topic, all differing in a number of basic assumptions. One of the main current hypotheses, sometimes referred to as the neuromaturational account (see [99,136, 155]), holds that there are important qualitative differences in memory skills between infancy and adulthood, which are explained by a sequential development of different memory systems throughout the course of early ontogeny [9,99]. One of the historical roots of this theoretical approach lies in the so-called Jacksonian hierarchical hypothesis, according to which those cognitive abilities that weaken firstly during aging are the last to emerge in ontogeny [35,66]. Following this argument, it was suggested, for example, that the implicit memory system, which allows the acquisition of certain basic forms of learning, would be functional from birth, while the explicit memory system would reach functional maturity later in ontogeny. The explicit memory system allows representations of contextually specific events and complex associations, and its function depends on the hippocampus and related structures of the medial temporal lobe [9,99,133,136,139]. In general, this hypothesis predicts that those behavioral and cognitive functions which depend on the hippocampus will emerge late in development.

Alternatively other authors have adopted a completely different approach to the development of cognitive functions. Their starting point was to consider the infant not as an immature organism, but rather as a different organism, perfectly matured and with specific behavioral and cognitive capacities which allow it to adapt appropriately to the demands of its environment in accordance with its maturational level [132–134,155,157]. Given that the environments to which organisms are naturally exposed throughout ontogenetic development undergo rapid, major changes, significant ontogenetic variations may be expected in what the organism perceives and selects during learning episodes [133,134,136,154,157]. Within this theoretical framework (which is known as the ecological model), infantile learning and retention capacities cannot be considered poorer or weaker than those of the adult organism; rather, these capacities allow the infant organisms to respond adaptively to their environment in each ontogenetic stage [131,133, 134,136,157]. This theoretical alternative was decisively influenced by the work of two authors (and their co-authors): N.E. Spear, who carried out his research with rats, and C. Rovee-Collier, who worked with preverbal human infants. The results of these two seminal research projects consistently showed that when infant organisms are evaluated in memory tasks whose testing demands are adapted to their perceptual and motor capacities, they are capable of acquiring complex forms of learning and can also respond accurately in tasks considered to be hippocampus-dependent [133,134,136,157].

Both theoretical models (the neuromaturational and the ecological) coincide in highlighting the relevance of studying the ontogeny of contextual learning, and each give rise to some important predictions. Since it assumes that contextual learning is hippocampus-dependent, the neuromaturational hypothesis predicts that, until the hippocampus reaches functional maturity, thus allowing adult-like memories, infants will have a limited capacity to acquire contextual learning, therefore, behavior and learning will be independent of the hippocampus [102]. From this perspective, the developmental analysis of contextual learning has been used as a marker to infer the possible sequential development of the explicit memory system and the brain structures underlying this type of memory. The hypothetical age limiting the emergence of hippocampal-dependent capacities was established at postnatal month nine in the human infant [105], and at the end of the preweanling period (postnatal day 21, PD21) in the rat [118,145]. In contrast, the ecological model does not necessarily predict a progressive development of contextual learning capacities [157]. Since infants and adults may differ in the way in which they attend to and encode information gleaned from learning episodes, this model predicts that there may be developmental differences in the way in which contextual information is incorporated into the memory, depending on the specific demands of the task [157]. Furthermore, this approach also expects that the detection of contextual learning and context effects during infancy may require the procedures to be adapted to the perceptual and motor capacities of the infant [157]. The early studies conducted by Spear and his co-authors on contextual learning during infancy were influenced by this ecological conception of development, as well as by his interest in memory development. Indeed, his first series of experiments exploring contextual fear conditioning in infants was designed with the aim of elucidating possible developmental differences in stimulus selection, which may be relevant for the understanding of infantile amnesia [81,90]. Spear also remarked on the importance of studying the ontogeny of contextual learning in relation to the relevance of incidental learning for the developing organism, with contextual learning being considered a specific example of this type of learning [81,159].

Although the debate about which of these approaches (neuromaturational and ecological) is more valuable for research within the developmental psychobiology framework may be considered overdrawn by some researches, the neuromaturational perspective still guides some developmental research. For example, in some cases it is still assumed that contextual learning during infancy should be exclusively dependent on the maturational level of the hippocampal memory system [114], or that the maturity of the hippocampus determines the context-dependence of interference learning [70]. In some cases the authors do not consider the procedural variables that may modulate this type of learning during this ontogenetic period. During the last decade important researchers in the field still considered this dichotomy relevant for discussing the interpretation of results from studies about the ontogeny of memory [133,134,136].

The present manuscript reviews those studies conducted over the past 30 years that have examined potential developmental differences in contextual memory. Research with both human and non-human animals on this topic has produced a wealth of knowledge, although it is striking to note also the diversity of results and discrepant conclusions regarding the infantile capacities underlying contextual learning and