Cognitive Development 29 (2014) 62–80

Contents lists available at ScienceDirect

Cognitive Development

# The development of attentional resolution

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ARTICLE INFO

*Keywords:*
Selective attention
Visual attention
Spatial resolution
Reading development
Dyslexia

ABSTRACT

Attentional resolution (He & Cavanagh, 1996) is defined as the smallest region in space that can be selected by visual attention. We investigated the development of attentional resolution of 7-, 9-, 11- and 13-year-olds and adults. We used a tracking paradigm with one target and varied the distance between target and distractors. Our results demonstrate that the resolution of attention develops markedly between childhood and adulthood. The developmental trajectory is characterized by a strong increase in attentional resolution between 7 and 9 years of age and a plateau at still immature performance between 11 and 13 years. The observed development of attentional resolution may be caused by the maturation of the neural networks responsible for the top-down deployment of visuo-spatial attention. Implications for reading acquisition are discussed.



## 1. Introduction

Selective attention can be defined as the ability to distribute one's limited processing resources according to current demands or goals (Carrasco, 2011). It is a multi-faceted concept that includes orienting to relevant locations or objects, sustaining attention and processing selectively parts within an environment while ignoring others (e.g., Chun, Golomb, & Turk-Browne, 2011). One aspect of visual selective attention is the maximum acuity one can apply while selecting items in one's environment. The scrutiny employed commonly depends on the demands of the task at hand; yet, at the same time,

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0885-2014/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.cogdev.2013.09.004

there seems to be a fundamental lower limit to the spatial precision with which certain details of a graphical surface can be examined. He and Cavanagh (1996) coined the term *resolution of attention* to define and describe the maximum spatial precision of selecting items for attention. This concept relates to the minimum size of the region selected by attention (Intriligator & Cavanagh, 2001) or, put differently, the finest spacing of objects that allows an observer to individuate a specific object in a dense array of multiple objects (He et al., 1997). Attentional resolution differs from visual acuity, which is defined as the minimum distance between two dots or lines at which the two objects can still be perceived as separate (Riggs, 1966). This becomes evident when the objects (e.g., lines) constituting the pattern of a stimulus configuration can be perceived as single objects but not individually selected (Intriligator & Cavanagh, 2001).

Research on the development of selective attention in children suggests that many aspects of selective attention develop throughout childhood (Ridderinkhof & van der Stelt, 2000; Scerif, 2010). Children are increasingly capable of efficiently deploying their attention (Hommel, Li, & Li, 2004; Ristic & Kingstone, 2009) and selecting relevant information while ignoring irrelevant information (McDermott, Pérez-Edgar, & Fox, 2007; Rueda et al., 2004). While changes in the general ability to select and ignore information have thus been targeted by research, little research has been undertaken to investigate any changes in the spatial characteristics of the focus of attention during selection and none explicitly determining the resolution of attention in children.

In adults, several studies have identified the lower spatial bound of attention. Intriligator and Cavanagh (2001) used an object tracking task (Pylyshyn & Storm, 1988) to determine the resolution of attention. They manipulated distance between objects by varying distance between display and observer, thus also concurrently changing the sizes of the tracking field and the objects being tracked. In this task, a number of identical objects are presented and one or several of the objects are marked as targets that need to be tracked. Subsequently, all objects move randomly about the screen for a certain period of time. After the objects have stopped moving, participants are asked to indicate which of the objects were the targets. In their version of the tracking experiment, Intriligator and Cavanagh (2001) varied the distance between objects.[1] They found that the critical spacing, i.e., the minimum spacing between targets and distractors before targets could no longer be individuated, was 5–6 min of arc (arcmin).[2] This result was replicated and refined within the same study using an attentional walk task. Here, observers were asked to move their attention between (static) discs in an array of identical discs that varied in density and eccentricity. The critical spacing for objects presented in the fovea determined by this task ranged between 2.6 and 6 arcmin, which is consistent with other studies that quantified the lower spatial limits of attentional selection (Landolt, 1891; Nakayama & Mackeben, 1989; Toet & Levi, 1992).

There are as yet no studies that have tried to precisely determine the resolution of attention in children. Only a limited number of studies with a related focus offer clues to how far children can attend to narrowly spaced objects and how this ability changes with age. Some initial insight can be gained from developmental studies using a variant of the flanker task (Eriksen & Eriksen, 1974), a paradigm in which the selection of a target from among congruous or incongruous flanker stimuli is investigated. In two of these studies, Enns and Girgus (1985), and Pastò and Burack (1997) examined the effect of a varying distance between target and flankers on the discrimination performance of differently aged children. Enns and Girgus (1985) compared the performance of 8- and 10-year-old children and adults at target-flanker distances of 0.5°, 2°, 4°, 8° and 16° visual angle. Pastò and Burack (1997) applied the same task to 4-, 5-, 7- and 9-year-olds and adults at target-distractor distances of 0.95° vs. 5.7°. Both studies show that flankers had to be located increasingly close to have an impact on the flanker effects of the respective age groups. This trend was confirmed by an additional flanker

[1] The term "critical spacing" originates from the literature on crowding and, in this context, is defined as the "distance over which the surrounding flankers degrade the identification of a target of a fixed size" (Jeon et al., 2010, p. 424). In the present article, *critical spacing*, in a more general sense, refers to the minimum distance between two objects (typically one target object and one distractor) before the distractor degrades the processing of the target.

[2] It is yet not clear, however, whether the final values observed by Bondarko and colleagues (Bondarko & Semenov, 2005; Semenov et al., 2000) conform to adult-like performance since no adult sample was tested.