Cognition 136 (2015) 156–165

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Multi-modal distraction: Insights from children's limited attention

Pawel J. Matusz [a,b], Hannah Broadbent [a], Jessica Ferrari [a], Benjamin Forrest [a], Rebecca Merkley [a], Gaia Scerif [a,*]

[a] Attention, Brain and Cognitive Development, Department of Experimental Psychology, University of Oxford, UK
[b] The Laboratory for Investigative Neurophysiology, Centre for Neuroscience Research, Department of Clinical Neurosciences and Department of Radiology, Centre Hospitalier Universitaire Vaudois and University of Lausanne, Switzerland

ARTICLE INFO

Article history:
Received 28 April 2013
Revised 13 September 2014
Accepted 17 November 2014
Available online 8 December 2014

Keywords:
Children
Selective attention
Attention development
Multisensory
Cross-modal

ABSTRACT

How does the multi-sensory nature of stimuli influence information processing? Cognitive systems with limited selective attention can elucidate these processes. Six-year-olds, 11-year-olds and 20-year-olds engaged in a visual search task that required them to detect a pre-defined coloured shape under conditions of low or high visual perceptual load. On each trial, a peripheral distractor that could be either compatible or incompatible with the current target colour was presented either visually, auditorily or audiovisually. Unlike unimodal distractors, audiovisual distractors elicited reliable compatibility effects across the two levels of load in adults and in the older children, but high visual load significantly reduced distraction for all children, especially the youngest participants. This study provides the first demonstration that multi-sensory distraction has powerful effects on selective attention: Adults and older children alike allocate attention to potentially relevant information across multiple senses. However, poorer attentional resources can, paradoxically, shield the youngest children from the deleterious effects of multi-sensory distraction. Furthermore, we highlight how developmental research can enrich the understanding of distinct mechanisms controlling adult selective attention in multi-sensory environments.

1. Introduction

The effectiveness of cognitive functioning in everyday life is determined by the ability to focus on a task while ignoring concurrent distracting stimuli (i.e., *selective attention*). Models of attentional selection were greatly advanced by "perceptual load theory" (e.g., Lavie, 1995, 2005, 2010; Lavie & Tsal, 1994), proposing that the extent to which such irrelevant stimuli are distracting is determined by the degree to which the currently performed task exhausts one's available attentional resources. This influential proposal operationalized "distraction" as interference on one's primary task by task-irrelevant stimuli and we shall here follow this convention. The current study demonstrates that studying distraction in real-life environments, multi-sensory by nature, can reveal other mechanisms important for controlling attention, and that their importance might be more readily witnessed by studying cognitive systems whose attentional control is developing (e.g., children).

1.1. Attentional allocation in unimodal environments

Lavie and Tsal (1994) argued that attentional resources, in particular their limited nature, are what determines whether stimuli irrelevant to the current task will be processed. Lavie and colleagues provided evidence for this

* Corresponding author.

http://dx.doi.org/10.1016/j.cognition.2014.11.031
0010-0277/

claim in a series of now classical studies that employed the response-competition task (Lavie, 1995; Lavie & Cox, 1997; Lavie & Tsal, 1994): Typically, when one is searching for one of two target letters (X or N) amongst a small number of letters (a task posing low perceptual load demands), concurrently presented peripheral distractors trigger reliable stimulus–response compatibility effects, i.e., slower search times on trials in which these peripheral stimuli prime a response opposite to the target response (e.g., an X when the target was an N). However, during search amongst a larger number of similar letters (a task posing higher perceptual load demands) compatibility effects are strongly reduced. In line with perceptual load theory (Lavie, 1995), in a task posing low perceptual demands, remaining attentional resources are automatically allocated to task-irrelevant stimuli in the environment. This results in distraction, as both target and distractors are processed up to the stage of their semantic representation and associated motor response. Such a situation contrasts with processing of distractors in a task that is perceptually demanding: Their processing is reduced or even eliminated, because the task is thought to be exhausting the available attentional resources.

1.2. Attentional allocation when faced with cross-modal distraction

While the importance of the nature of one's primary task in constraining distraction has since been replicated with various methods, measures and populations (see Lavie, 2010, for a review), of particular value is testing whether predictions of perceptual load theory hold against everyday situations, such as in the context of cross-modal distraction. Early seminal work by Allport and colleagues (e.g., Allport, Antonis, & Reynolds, 1972) had demonstrated that a fairly complex auditory task (i.e., auditory shadowing) can be performed alongside a demanding visual task (i.e., sight-reading music), which suggests a limited effect of processing load across senses. Further contrasting evidence was provided by Tellinghuisen and Nowak (2003), who used a version of the response-competition task adapted to a cross-modal context: When peripheral letter distractors are presented auditorily during search for visual letter targets, they, unlike visual distractors, filter into further processing stages, causing interference under conditions of high visual perceptual load.

The residual interference effects from auditory distractors on visual tasks have been presented as evidence for separate attentional resources in vision and audition. Visual distractors do not impact attention on the primary task, presumably because attentional resources in the primary modality have been depleted, whereas separate resources are devoted to auditory distractors (Duncan, Martens, & Ward, 1997; Welch & Warren, 1980). However, recent studies have provided mixed evidence for this account (Jacoby, Hall, & Mattingley, 2012; Klemen, Büchel, & Rose, 2009; Parks, Hilimire, & Corballis, 2011). For example, high visual perceptual load was recently shown to induce inattentional deafness: Macdonald and Lavie (2011, Experiment 3) instructed participants to judge which of two coloured arms of a centrally presented cross was longer, while on some trials a task-irrelevant pure tone was presented. On trials where the two arms differed in length only slightly (a perceptually demanding task), conscious awareness of the tone was reduced compared to trials in which the difference in arm length was larger (a task with lower perceptual demands). In contrast to separate-resources models, these results indicate that in adults, even in cross-modal contexts, at least under some conditions (e.g., very high visual load and/or complete task irrelevance of the auditory distractor) attentional resources are shared across modalities.

1.3. Attentional allocation in multi-sensory environments

The jury is therefore still out on whether cross-modal distraction can be entirely removed by increases in visual attentional load and on what drives cross-modal distraction, i.e., interference, on a visual task. Particularly informative to this debate are studies employing stimuli that present redundant information to more than one modality at once (e.g., Matusz & Eimer, 2011, 2013; Van der Burg, Talsma, Olivers, Hickey, & Theeuwes, 2011). Multiple sources of congruent information are integrated into a unified multi-sensory percept that triggers enhanced behavioural and/or neural responses, both when the information is redundant at a low perceptual (e.g., temporal and/or spatial alignment; e.g., Santangelo & Spence, 2007, but see Spence, 2010) or high semantic level (e.g., Laurienti, Kraft, Maldjian, Burdette, & Wallace, 2004; for a review, see Alais, Newell, & Mamassian, 2010). However, this body of research has tended not to use the classical visual perceptual load paradigms. Yet, this novel extension is much needed, as it would bridge the perceptual load theory of selective attention and theories of multi-sensory processing, which traditionally have been developed separately. Do increased perceptual demands of the primary task reduce distraction elicited by multi-sensory events? If audiovisual distractors were processed under both lower and higher visual load, this would provide further support for the idea that, at least under some conditions, separate attentional resources are deployed (Tellinghuisen & Nowak, 2003). Interestingly, multi-sensory distractors should generally result in more robust distraction (i.e., interference on the primary task) than unimodal distractors because at each level of visual perceptual load they would engage attentional resources in two modalities. If such effects were indeed observed, this would call for a revision of the perceptual load theory to accommodate multi-sensory distraction.

1.4. Insights from developmentally-informed research

Some of the strongest evidence for the critical role of attentional resources in reducing distractor processing has been provided by research involving young children, whose attention is known to be less efficient than that of adults (e.g., Plude, Enns, & Brodeur, 1994; Trick & Enns, 1998). In a version of the response-competition task, Huang-Pollock, Carr, and Nigg (2002) found that children as young as seven years of age were more distracted by peripherally-presented letters than young adults when