ISSN 1452-7367
Vol. 10, br. 1. 2011.

UNIVERZITET U BEOGRADU
FAKULTET ZA SPECIJALNU EDUKACIJU I REHABILITACIJU
IZDAVAČKI CENTAR - CIDD

SPECIJALNA EDUKACIJA I REHABILITACIJA

SPECIAL EDUCATION AND REHABILITATION

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Beograd, 2011.

Izdavač
Univerzitet u Beogradu
Fakultet za specijalnu edukaciju i rehabilitaciju
Visokog Stevana 2, Beograd
Izdavački centar - CIDD

Za izdavača
Prof. dr Jasmina Kovačević, dekan

Tiraž
200

Štampa
„Planeta Print", Beograd

ISSN 1452-7367

Časopis izlazi četiri puta godišnje. Od 2010. godine u finansiranju časopisa učestvuje Ministarstvo za nauku i tehnološki razvoj Republike Srbije.

Beograd, Visokog Stevana 2, 2920 451,
Email: pdnauka@fasper.bg.ac.rs

Publisher:
University of Belgrade
Faculty of Special Education and Rehabilitation
Visokog Stevana 2, Belgrade
Publishing Center - CIDD

For the Publisher
Prof. Jasmina Kovačević, PhD, Dean

Editor-in-Chief
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Serbian Proofreading
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Number of copies: 200

Printed by:
„Planeta Print”, Belgrade

ISSN 1452-7367

Published four times a year. Financial support since 2010: Ministry os Science and Technological Development of the Republic of Serbia

Belgrade, Visokog Stevana 2, +381 11 2920 451,
Email: pdnauka@fasper.bg.ac.rs

Specijalna edukacija i rehabilitacija
(Beograd), Vol. 10, br. 1. 77-92, 2011.

UDK: 159.952-053.2 ;
159.922.72-053.2
ID: 183890444
Pregledni rad

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DEVELOPMENTAL CHANGES IN AUDITORY ATTENTION[2]

This paper presents an overview of developmental findings on auditory attention and its main components. Unlike visual attention that has been excessively studied in infants and children, auditory attention studies in the youngest population are sparse. However, during the last decade, there has been an increase in the number of studies, especially electrophysiological ones carried out on infants. Our review starts with Posner's seminal theoretical and experimental work gradually developing into a neuropsychological model of attention. Basic components of auditory attention are presented with the focus on selective auditory attention and the MMN as its electrophysiological correlate. In conclusion, we return to the psychological concepts of interpreting developmental changes in auditory attention. The psychological level of analysis shows interconnectivity of all attentional components as well as the relation between attention and other aspects of cognitive and emotional development.

Key words: *auditory attention, selective attention, developmental changes, cognitive neuroscience*

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2 AKNOWLEDGEMENT
This research study was supported by the Ministry of Science and Technological development of the Republic of Serbia under project no. 178027 „Interdisciplinary research of verbal communication quality”

Studies of auditory attention development are a part of a relatively young field of research, with a greater number of studies dedicated to infant's and children's visual attention (Richards & Colombo,2005; Colombo, 2002, Trick & Enns,1998). Studying attention in general is a hard to define area because of the nature of attention as a process. Attention has been characterized as such an elusive concept because it is activated in numerous cognitive processes, allowing the cognitive system „to successfully process some sources of information to the exclusion of others, in the service of achieving some goals to the exclusion of others" (Cohen et al. 2004, p.71). This is why most attention studies need to handle the problem of separating attention from encoding, memory and other steps in the complex stream of information processing.

Attention has been in focus of research of dominantly behavioral psychology, with recent slow convergence of findings from animal studies, PET and EEG studies (these include recordings from restricted brain areas including single cell recordings in animals) creating the field of cognitive neuroscience.

The attention system and its neural networks

The currently accepted neuropsychological model of attention has been proposed by Posner (Posner et al. 1980, 1994, Posner & Rothbart, 1998) and can be summed up as follows. The attention system of the brain is independent, anatomically separate from other systems that process information, through its interactions with other systems. It is carried out by a network of areas. These areas perform different functions which can be specified in cognitive terms (Posner et al. 1980; Posner &Petersen, 1990; Posner, 1980, 1994). Posner describes the attentional system through two levels, which is important for our developmental view. Development occurs through the attentional system gaining voluntary control over more automatic brain systems (Posner & Petersen, 1990) or, in other words, from subcortical to cortical control of attention. When infants develop into toddlers, the executive control system begins to mature, involving areas of the frontal cortex, in particular the prefrontal cortex (Weijer-Bergsma et al. 2008; Fisher, 2007; Richards & Colombo,2005; Richards, 1998).

Growing evidence from neuroscience shows that the function of attention encompasses three separate networks in the brain (Fan et al. 2005, Callejas et al, 2004, Posner & Petersen, 1990, Waszak et al. 2010). These are 1) alerting 2) orienting and 3) executive function. FMRI results of Fan and colleagues (Fan et al. 2004) show fronto-parietal cortical activation along with the thalamus in alerting. In orienting, activity can be found in the left and right superior parietal lobe. Response conflict is located in the anterior cingulate plus right and left frontal areas.

Fan and colleagues have designed an Attention Network Test encompassing all of these functions in specific experimental tasks. Using reaction time as a measure of efficiency in each of these tasks, no correlations were found confirming the hypothesis on separate neural networks showing independent functioning. These results were in accordance with neuroimaging studies (Posner, 1994)

Components of auditory attention

In their concise overview of auditory attention development research, Gomes and colleagues (Gomes et al. 2000) have defined auditory attention through its four components: arousal, orienting, selective attention and sustained attention. We shall present each of these components, their developmental trajectory and hypothesized neural basis. More attention will be paid to selective attention which is a central component in the attention system, with bigger implications for learning and development.

Arousal is the psychological readiness to perceive and process stimuli. It is assumed that it's a two level system consisting of a lower physiological level mediated by the reticular formation, and the higher, cognitive level located in the right frontal lobe. The first system is established early in development, while the second system develops later. The cognitive arousal system develops jointly with self-regulatory functions[3]. Data on the development of this network has come from behavioral observations of sustained attention during play,

3 Self-regulation is the process of voluntary control over different dimensions of the self, including emotion, cognition. Self-regulation encompasses skills such as paying attention, inhibiting reflexive actions, and delaying gratification

video watching and more or less structured tasks (Weijer-Bergsma et al. 2008). Orienting refers to the physiological and behavioral changes associated with detection of a novel stimulus. In infants, orienting has been studied relative to features of the stimulus. The behavioral signs used were localized head turning, heart rate deceleration, and motor quieting. The same as with other attention components, more studies have been carried out in the domain of visual attention. It has been registered in infants as well as near term fetuses. Recovery of the orienting response has been shown in infants with different stimuli such as tone burst, an altered rattle sound, a new pulsed synthetic vowel, a change in the initial consonant of a syllable, and a new two syllable nonsense word (Gomes et al. 2000). Some data on auditory stimuli shows larger orienting responses to high frequency than low frequency noise, pulsed than continuous signals. The efficiency of orienting seems to increase with age: 5- to 9-year-old children show a larger validity effect than adults, presumably because they are less effective at redirecting attention from the wrongly cued location to the target. Selective attention is the process whereby the individual focuses on a specific stimulus or stimulus stream for the purpose of processing the information more fully while ignoring other, potentially distracting, stimuli. Selective attention to stimulus dimensions has been conceptualized as the differential weighting of dimensions in perceptual decisions, as in similarity judgments, classification, attentional learning and in neurocomputational models of cognitive control (Hanania & Smith, 2009). This is why it is an important focus of study in connection with learning and development. Most auditory attention data has been collected indirectly, through studies of language perception and processing with the inability to clearly differentiate phases of cognitive processing (attention, encoding, remembering, comparing, responding). In infants, this has been carried out through the behavioral paradigms of high amplitude sucking and head turning. Infants have shown preference for mother's voice over female stranger's voice, prosody of native language vs. prosody of foreign language. Data from electroencephysiological studies (the MMN[4] as a component of ERP, which will be presented in

4 MMN or mismatch negativity is the component of event-related potential and the brain's automatic response to detection of change in auditory stimuli. It is a possible neurophysiological basis of sound discrimination

more detail later in the text) show elicited MMNs for tones differing in frequency and syllables differing in place of articulation and voice onset time. Larger MMN was obtained for speech than non-speech stimuli. Minimal changes in speech sounds were obtained even in pre term infants, neonates and infants during the first year of life (Cheour et al. 2000). Sustained attention is considered by some an element of arousal, the ability to maintain attentional focus over time. It is assessed through change in the number of correct detections as a function of time on task. In infants, it is detected by physiological and brain changes. When these parameters start to wane, attention drops. In sustained attention, infants are better able to resist peripheral distracters and show superior memory encoding and enhanced identification of briefly presented stimuli. Sustained attention is likely controlled by neurotransmitter systems in the brain that control „arousal" or „attentiveness" (Richards & Colombo,2005). On the neuropsychological level, studies have implicated the importance of right hemisphere sites. In a positron emission tomography (PET) study, Pardo and colleagues (Pardo et al.1997) had subjects continuously monitor subtle changes in both visual and somatosensory stimuli and found strong activation in right hemisphere superior parietal sites and in right hemisphere prefrontal sites for both types of stimuli. Results in the development of sustained auditory attention are few, showing controversial results regarding developmental changes in this component of attention due to possible intervening factors in task performance such as motivation. Some studies show the increase of sustained auditory (and visual) attention in school aged children (Brown, 1982).

An interesting study viewing sustained attention as a dynamic process, in interaction with modality and temperament showed that intermodal relations changed with age: Performance across modality was significantly correlated for children but not for adults. Although temperament did not significantly predict performance in adults, it did for children. The temperament effects observed in children-specifically in those with the composite of reactivity-occurred in connection with the auditory task (Curtindale et al. 2007).

Selective auditory attention studies in children: neurocognitive and behavioral measures

Using data from electroencephalography, we can uncover neural mechanisms underlying cognitive processes in infants and children. Until recently, data on neuronal levels of many cognitive processes as well as attention relied on two sources: studies of animals and behavior of infants. For certain types of behavior, a connection with specific areas of the brain was hypothesized. Advances in cognitive neuroscience were achieved primarily through PET studies and the EEG and ERP. More recently, non-invasive neuroimaging tools have been developed for use with infants. One approach is to apply „near infrared optical spectroscopy" (NIRS or „optical topography", OT). The NIRS measures blood flow in cortical areas near the surface of the cortex with infrared detector/emitter pairs placed on the surface of the head. Areas of the brain that are active during a psychological task will receive increased blood flow during and following that task, so that the blood flow changes are a measure of which areas of the brain are involved in the psychological processes for that task (Richards, 1998).

Recording brain activity during auditory attention has been most frequently studied using the oddball procedure where two auditory stimuli are presented. One of them is a standard stimulus, presented frequently, while the other is the deviant stimulus, presented infrequently (this what the term oddball refers to). This procedure elicits the brain's normal change detection response called MMN (mismatch negativity) and is considered a component of the ERP (event-related potential). According to Naaatanen who first isolated the MMN from wave N2[5], it reflects an automatic pre-attentional change-detection process, comparing the new auditory input with information stored in auditory sensory memory. Naatanen has argued the MMN is a component specific to the auditory system. Using the MMN in child studies has important advantages - it does not require an overt behavioral response or active discrimination from the subject (Richards, 1998; Cheour et al, 2000; Nataanen, 1995, Kurtzberg et al. 1995, Bishop, 2007).

5 The N2 is a negative-going wave that peaks 200-350ms post-stimulus and is found primarily over anterior scalp sites. Past research focused on the N2 as a mismatch detector, but it has also been found to reflect executive cognitive control functions, and has recently been used in the study of language

It is hypothesized that the MMN consists of at least two subcomponents at the neural level. One is sensory specific and located in the primary and secondary auditory cortices, while the second is in the frontal cortex, presumed to be involved in involuntary detection of the deviant stimulus. MMN also may have subcortical components. Studies carried out on animals have pointed to MMN-like negativity over the medial geniculate body (MGB) of the thalamus and the dorsal hippocampus to changes in tones. Kraus and colleagues (Kraus et al. 1995) have recorded MMN from the auditory thalamus of guinea pigs.

There is evidence of auditory-change detection components in infants. In the majority of studies, a positivity peaking at about 300 ms was observed (Csibra et al. 2008). An early negativity peaking at about 150 ms was obtained only in response to frequency change with grossly deviating stimuli and was suggested to be related to spectral change of acoustic parameters (Kushnerenko et al., 2006). Another component that can be obtained in the passive oddball paradigm is the P3a[6], a fronto-centrally maximal positivity elicited by stimuli that catch attention. 'Novel' sounds among pure tones are often used to elicit the P3a. Such grossly deviating stimuli typically elicit a large P3a response in children and adults (Gomes et al.,2000). This has also been found in newborns (Kushnerenko, 2006) but this result is interpreted as elicited by the spectral richness of the novel sounds. The P3a is sometimes followed by a frontal negativity at 500-600 ms latency in children's and infants' auditory ERPs. This late negativity is larger in amplitude in younger than in older children: the same maturational profile that has previously been reported for the negative component Nc (Courchesne, 1983). This negative component has been suggested to be a sign of enhanced auditory and visual attention, since it was elicited in response to surprising, interesting, or important stimuli (Courchesne, 1978).

Berman and Friedman (Berman & Friedman, 1995) carried out a study on different age groups, ranging from eight years of age through adolescence and adulthood, focusing on selective attention of pure tones and vowels vs. consonants, using the oddball paradigm. Subjects were required to attend to one of the two stimuli in order to detect a deviant target embedded within the attended sequence,

6 An ERP (positive-going)connected with brain activity related to attention

while ignoring the sequence comprised of the other stimulus (which also contained standard and deviant stimuli). A major effect of age was found on reduction of negative-going ERP amplitude elicited by stimuli in the unattended channel, suggesting that with age there is an improvement in the narrowing of the attentional focus and the capacity to reject irrelevant stimuli. This is in accordance with the Gomes study (Gomes et al, 2000) comparing the MMNs elicited by deviant stimuli when they were ignored and when they were attended to. In the attended to condition, subjects were instructed to press a button when they hear a deviant stimulus; all deviant stimuli, even the hardest to discriminate, elicited MMNs from children in contrast to when the stimuli were to be ignored. Adults exhibited MMNs for all attended and ignored deviants in this study. These data suggest that the discrimination of relatively hard to detect differences requires that children actively attend to the stimuli, whereas in adults such processing appears to be automatic.

Van der Molen and colleagues (Van der Molen et al. 2000) measured heart rate in a sample aged 7 to 20 in an auditory selective attention task. The absence of differential sensitivity of heart rate responses to rare tone pips presented at the unattended ear was observed for all age groups. These findings were interpreted to suggest that the ability to ignore irrelevant target stimuli has reached mature levels during middle childhood. The depth of anticipatory heart rate deceleration increased until age 14, suggesting that the ability to maintain attentional set continues to develop beyond childhood.

Studies of visual attention have shown similar results concerning children's inefficiency when interfering stimuli are presented. Enns (1990) argued that it can be attributed to inefficient selection at the perceptual end of the processing chain. However, Ridderinkhof and van der Molen (1995) compared 5- to 12-year-old children and young adults. Measures derived from ERPs (event-related potentials) suggested that incongruent stimuli delay both stimulus evaluation and response activation. However, there was no difference in the interference effect on stimulus evaluation between age groups. By contrast, the interference effect on correct response activation showed a pronounced age-related reduction, suggesting that response competition is the major source of developmental differences in the ability to resist interference - that is, inefficient selection at the output end of the processing chain. Goldberg, Maurer, and Lewis (2001) showed that 8- to10-year-olds are slowed more than adults by incompatible distracters. In the same study they showed that attention orienting (endogenous in this case) is already adult-like by 8 to 10 years of age. The authors concluded that the ability to filter out irrelevant information develops comparatively late.

Conclusion: developmental changes

Auditory attention development is a relatively young field of research, and it therefore currently lacks a model that would encompass different aspects of attention in its developmental context, while several neuropsychological models can be found for children's visual attention. Posner pointed out the need to define some general mechanisms as well as modality specific mechanisms when considering the human attentional system (Posner et al. 1980, 1994, Posner & Rothbart, 1998). According to Posner, attentional selectivity requires a multilevel hierarchical system with a lower level dedicated to each particular cognitive system and higher levels that are general across different cognitive systems. The mechanisms responsible for early attentional preferences are probably closely linked to specific sensory systems and may be sensitive to physical differences in the types of information processed by these modalities.

How to account for developmental changes?

Review of experimental studies and their conclusions, shows developmental changes from more engaged attentional processes towards automatic processing, corroborated by the neural level of analysis. How to account for these developmental changes? One of the key psychological concepts is that of *learning*. The cognitive system depends on focused attention until a skill is acquisitioned. It is then moved to an automatic level of processing. This is the process of learning. In other words, prior knowledge and experience becomes more effective with time, resulting in more successful allocation of attention and prolongation of sustained attention.

The second general conclusion reviewing developmental studies concerns the transition towards voluntary attentional control which is obvious when different age groups are compared. The terminology in use is the top-down attention control. Top-down processing includes the flow of information from „higher" to „lower" centers, conveying knowledge derived from previous experience rather than sensory stimulation (Corbetta & Shulman, 2002). Kalinli and Narayanan describe an auditory attention top-down model: a neural mechanism exists that selects a subset of available sensory information before fully processing it. A stimulus-driven bottom-up process of the whole scene attracts attention towards salient locations in an unconscious manner. Then, the top-down processing shifts the attention voluntarily towards locations of cognitive interest. Only the selected location is allowed to progress through the cortical hierarchy for high-level processing to analyze the details (Kalinli & Narayanan, 2008). In other words, the first stage of development is more stimulus-driven moving towards person driven or voluntary control (Fisher, 2007). Theories of executive function propose that the executive system modulates lower level schemas according to the subject's intentions. In the absence of an executive system, information processing loses flexibility and becomes increasingly bound to the external stimulus (Fernandez-Duque et al. 2000). Research shows that young preschoolers have underdeveloped executive control of selective attention, or the ability to disengage from salient information and switch attention among stimulus dimensions. This has been attributed to underdeveloped prefrontal cortex (Bunge et al. 2002). Neuroimaging and postmortem analyses of the brain structures of humans and non-human primates indicate that PFC (the prefrontal cortex) is one of the last brain areas to mature. (Bunge et al., 2002; Fisher, 2007). In studies of selective auditory attention, different age groups show movement from processing of irrelevant stimuli to their gradual inhibition in light of effective focused or sustained attention.

In context of executive attention, another important concept is that of self -regulation, also used to account for developmental changes in experimental tasks focused on auditory attention. The function of self-regulation has been tied to the development of the prefrontal lobe. Between the ages of 3 and 6, these brain regions become more mature, children show improved ability in impulse control and flexible attention shifting, amongst other skills. This system is the source of attention and operates in conjunction with other structures to carry out specific cognitive and emotional computations. (Posner & Rothbart, 1998; Sheese et al. 2008).

Gomes and colleagues (Gomes et al, 2000) use another psychological concept to explain the difference between age groups: *representation of stimuli*. Trying to explain the difference in performance in selective auditory attention tasks using the oddball paradigm, they hypothesize that children have poorer representation of the standard stimuli compared to adults. Poorer representation leads to less successful discrimination. This explanation could also be used on performance in allocation of attention tasks.

Significance of auditory attention in development

When discussing different sensory modalities, auditory vs visual attention is given a special role in language acquisition research. In studying auditory attention in its developmental context, it is important to include these studies that could shed light on the possible dominance of the auditory modality in certain periods of development. Research shows its dominance compared to the adult period (Lewkowitz, 1994; Sloutsky and Napolitano, 2003). Authors draw on several reasons for this phenomenon, such as 1) earlier maturation of the auditory system compared to the visual, 2) the importance of auditory modality in the period of language acquisition 3) attentional demands are smaller for auditory stimuli compared to visual stimuli (duration of stimulus for example) 4) adults may have a bias that comes from knowledge that visual entities are likely to be objects, while auditory presented entities are likely to be events, whereas children have not developed this bias yet (hence the visual dominance in adult population).

To conclude, we have presented a relatively fragmented area of auditory attention development research through some of its components. We have highlighted selective attention as the component which is the most important for learning and has therefore been studied most extensively, especially in electrophysiology. We also claim that placing auditory attention in its developmental context unavoidably leads to the major developmental issue of language acquisition. The psychological level of interpretation shows us our guideline in clearly defined cognitive processes and their connection to emotional and motivational aspects of personality. No doubt that new empirical findings are needed in order to form a comprehensive neuropsychological model of development of auditory attention.

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Specijalna edukacija i rehabilitacija (Beograd), Vol. 10, br. 1. 77-92, 2011.

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Rezime

Rad predstavlja pregled razvojnih istraživanja u okviru auditivne pažnje i njenih glavnih komponenti. Za razliku od vizuelne pažnje odojčadi i dece, istraživanja auditivne pažnje kod najmlađe populacije su daleko manje prisutna. Međutim, poslednja dekada beleži porast istraživanja posebno onih koja primenjuju elektrofiziološke parametre. Pregled počinje prikazom Posnerovog rada koji je rezultirao uticajnim neuropsihološkim modelom pažnje. U okviru prikaza auditivne pažnje, predstavljamo osnovne komponente ove funkcije, sa akcentom na selektivnu auditivnu pažnju i MMN kao njen glavni elektrofiziološki korelat. U zaključku se oslanjamo na psihološki nivo interpretacije razvojnih promena u auditivnoj pažnji. Ovaj nivo pokazuje međusobnu povezanost svih komponenti pažnje, kao i vezu auditivne pažnje sa kognitivim i emocionalnim dimenzijama ličnosti.

Ključne reči: auditivna pažnja, selektivna pažnja, razvojne promene, kognitivne neuronauke

Primljeno, 9. 3. 2011. *Prihvaćeno, 28. 3. 2011.*