

Role of Mismatch Negativity and Novelty-P3 in Involuntary Auditory Attention

Carles Escera and M.J. Corral

Cognitive Neuroscience Research Group, Department of Psychiatry and Clinical Psychobiology, Faculty of Psychology, University of Barcelona, Catalonia-Spain

Abstract. It has been proposed that the functional role of the mismatch negativity (MMN) generating process is to issue a call for focal attention toward any auditory change violating the preceding acoustic regularity. This paper reviews the evidence supporting such a functional role and outlines a model of how the attentional system controls the flow of bottom-up auditory information with regard to ongoing-task demands to organize goal-oriented behavior. Specifically, the data obtained in auditory-auditory and auditory-visual distraction paradigms demonstrated that the unexpected occurrence of deviant auditory stimuli or novel sounds captures attention involuntarily, as they distract current task performance. These data indicate that such a process of distraction takes place in three successive stages associated, respectively, to MMN, P3a/novelty-P3, and reorienting negativity (RON), and that the latter two are modulated by the demands of the task at hand.

Keywords: evoked potentials, audition, involuntary attention, orienting response, stimulus-driven attention, top-down modulation

Shortly after the discovery of the mismatch negativity (MMN) phenomenon in 1978 by Näätänen and colleagues (Näätänen, Gaillard, & Mäntysalo, 1978), as an event-related brain potential (ERP) elicited to auditory stimuli deviating from a repeating sound, Näätänen and Michie (1979) proposed that the underlying generating process would be implicated in issuing a call for focal attention upon the detection of an unexpected auditory change in the acoustic environment. This proposal was further elaborated in subsequent theoretical papers (Näätänen, 1990, 1992), but had to wait for about 20 years to find the appropriate empirical support. A study by Erich Schröger which appeared in 1996 (Schröger, 1996), was the first to demonstrate that the occurrence of an MMN-eliciting tone, deviating in frequency from the standard stimuli in the unattended channel of a selective attention task, impoverished behavioral performance to a subsequent target occurring in the attended channel. Moreover, this effect was restricted to a short latency window between the unattended deviant and the attended target, i.e., 200 ms, but disappeared when this interval was extended to 560 ms. Furthermore, the magnitude of the effect was related to the magnitude of the deviant-standard frequency difference, i.e., the behavioral cost was larger for larger deviants. All in all, this pattern of results strongly pointed out to a role of the MMN-generating process in involuntary attention.

Two years later, Schröger and Wolff (1998a) and Escera and colleagues (Escera, Alho, Winkler, & Näätänen, 1998) published studies that, using different but related

experimental approaches, provided strong support for the role of the MMN underlying process in involuntary attention. In their designs, subjects were instructed to classify auditory (Schröger & Wolff, 1998a) or visual (Escera et al., 1998) stimuli while ignoring concurrent, task-irrelevant auditory information. Systematically, the occurrence of MMN-eliciting, stimulus changes in the task-irrelevant auditory channel decreased hit rate and prolonged response times in the auditory or visual classification task, i.e., “distracted” current task performance. Moreover, this “distracted” performance was accompanied by a pattern of brain responses, later named the distraction potential (DP) by Escera and Corral (2003), which included the MMN, the P3a or novelty-P3 (depending of the type of auditory distracter stimuli used), and a new ERP component discovered by Schröger and Wolff (1998b) in this context of behavioral distraction, named reorienting negativity (RON).

Subsequent studies using similar distraction paradigms extended these findings and provided the building blocks for a model of involuntary attention. The present review extends our previous ones (Escera, Alho, Schröger, & Winkler, 2000; Escera & Corral, 2003) and aims at summarizing these involuntary attention studies, with an emphasis on those using the auditory-visual distraction paradigm. We also aim at outlining a neurocognitive model on how the attentional system controls the flow of bottom-up auditory information in the context of the ongoing-task demands to organize goal-oriented behavior.

Auditory Distraction

In the auditory-auditory version of the distraction paradigms, subjects are instructed to concentrate on a particular dimension of the auditory stimuli, i.e., duration, while ignoring any other aspect of the auditory input, i.e., a task-irrelevant and rare change, say, in frequency. The sequence is arranged so that, in random order, half of stimuli have a particular duration, while the other half are longer; the subject is instructed to press the corresponding response button according to stimulus duration. In a few of the trials, the

standard frequency is slightly increased or decreased, and this task-irrelevant frequency change, which elicits a distinct MMN, yields also a behavioral cost in the duration discrimination task: Subjects respond more slowly and make more errors in these “deviant” trials (Schröger & Wolff, 1998a,b; Schröger, Giard, & Wolff, 2000). Subsequent studies have shown that the magnitude of the distracting effects was proportional to the frequency difference between the deviant and the standard tones (Berti, Roeber, & Schröger, 2004; Jääskeläinen, Schröger, & Näätänen, 1999), as previously observed by Schröger (1996), and that

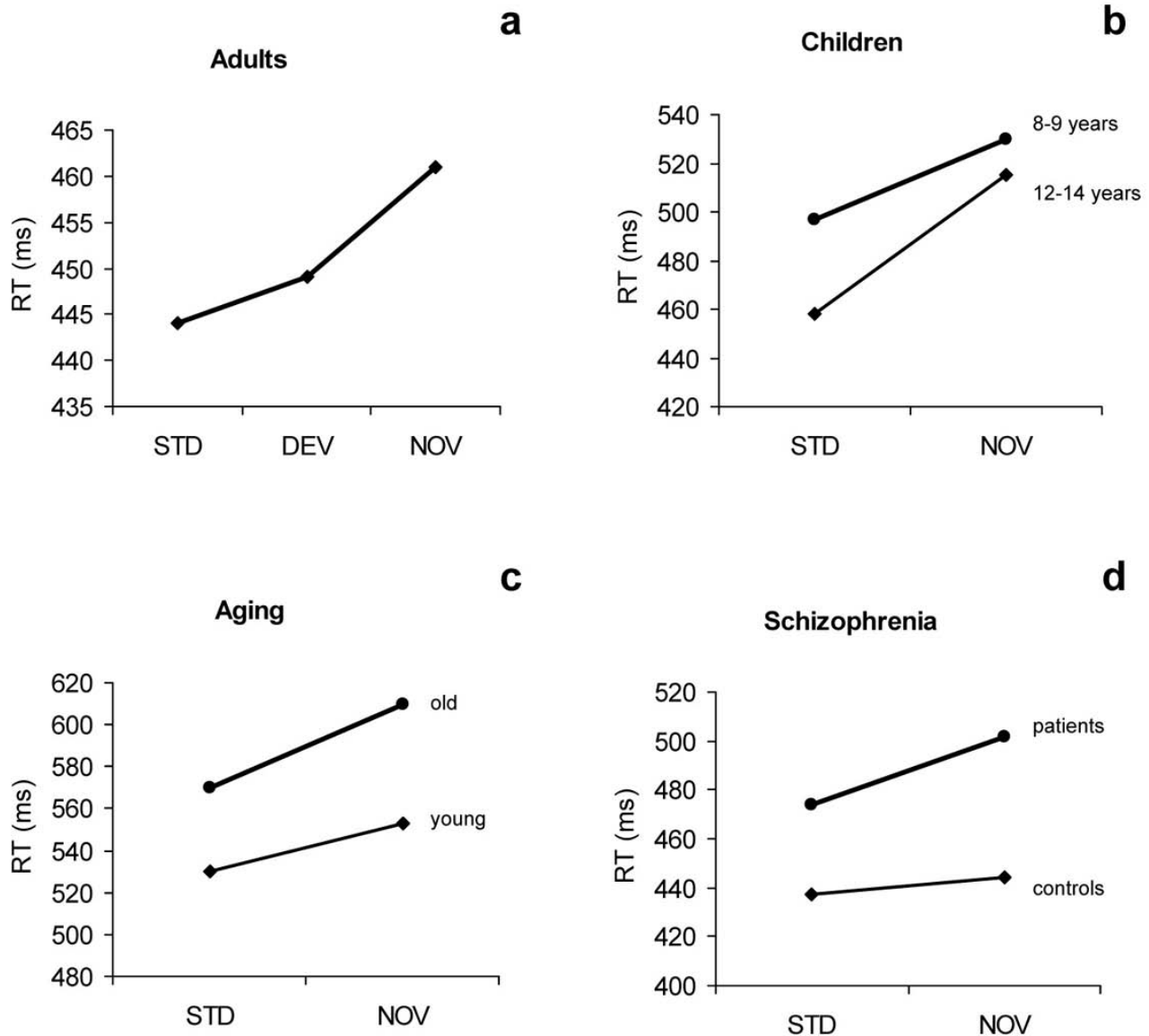


Figure 1. Behavioral examples of auditory distraction obtained with the auditory-visual distraction paradigm. Auditory distraction is observed as an enlargement of response time (RT) in trials containing a distracting sound, i.e., a deviant tone (DEV) or a novel sound (NOV), compared to RT in standard trials (STD). (a) Distraction caused by deviant tones and novel sounds in healthy adults (adapted from Escera et al., 1998). (b) Distraction caused by novel sounds in children (adapted from Gumenyuk et al., 2004). (c) Distraction caused by novel sounds in young and old adults: notice the larger distraction in the older (adapted from Andrés et al., 2006). (d) Increased distraction in schizophrenic patients (adapted from Cortiñas et al., submitted).

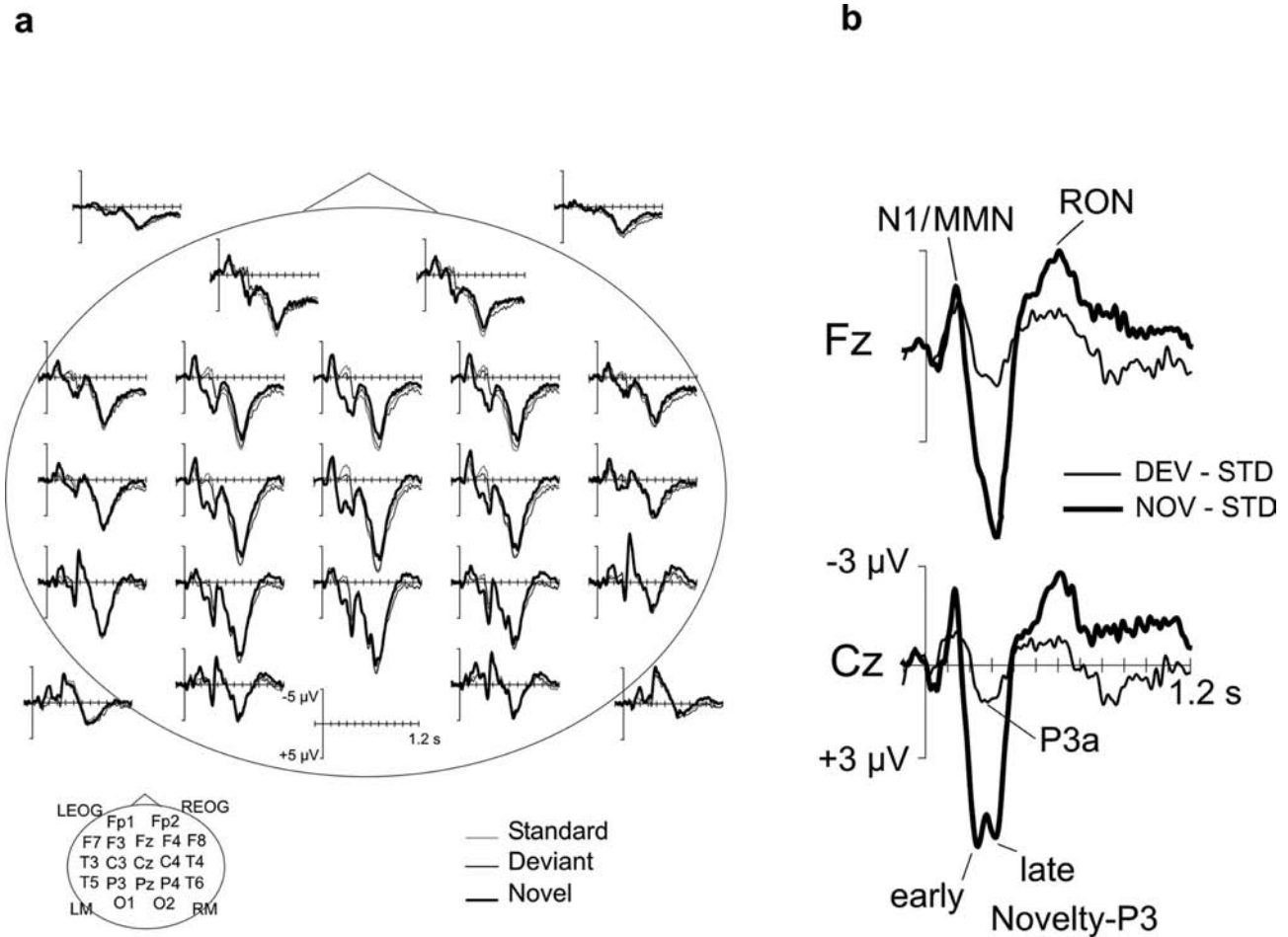


Figure 2. The distraction potential (DP). (a) Event-related brain potentials elicited to standard, deviant, and novel trials during visual task performance while ignoring the auditory stimulation. (b) Subtraction waveforms (distracting, i.e., deviant and novel, minus standard trials) revealing DP. The DP appears as a three-phasic waveform disclosing the contribution of MMN, N1-enhancement, P3a/novelty-P3, and RON. Data in the figure are taken from Escera et al. (2001).

similar behavioral and electrophysiological effects could be elicited using intensity (Rinne, Särkkä, Degerman, Schröger, Alho, 2006), and location and duration deviances (Roeber, Widmann, & Schröger, 2003). Moreover, the paradigm provides reliable and replicable behavioral and electrophysiological results (Schröger et al., 2000), and it has proved to be suitable to study involuntary attention in children (Wetzel, Widmann, Berti, & Schröger, 2006; Wetzel & Schröger, 2007a,b), and with a modified version using animal sounds instead of pure tones, even in children as young as 5 or 6 years of age (Wetzel, Berti, Widmann, & Schröger, 2004).

In the auditory-visual version of the distraction paradigm, subjects are instructed to classify visual stimuli into two particular categories, as quickly and accurately as possible, and to ignore concomitant auditory stimuli, which are presented one at a time preceding the visual stimulus, usually with a stimulus-onset asynchrony (SOA) of 300 ms, onset-to-onset. These task-irrelevant sounds are manipulated conveniently, so that the “standard” stimulus (occurring

in 80% of the cases) is occasionally and randomly replaced by a “distracter,” i.e., a stimulus slightly higher/lower (“deviant”) in frequency or by a unique environmental (“novel”) sound (i.e., telephone ringing, a glass breaking, or the one produced by a drilling device). In the original version of the task, subjects were instructed to classify digits into odd and even categories (Alho, Escera, Díaz, Yago, & Serra, 1997; Escera et al., 1998; Escera, Yago, & Alho, 2001; Escera, Corral, & Yago, 2002; Escera, Yago, Corral, Corbera, & Nuñez, 2003; Jääskeläinen, Alho, Escera, Winkler, Sillanaukee, & Näätänen, 1996; Yago, Escera, Alho, & Giard, 2001a; Yago, Escera, Alho, Giard, & Serra-Grabulosa, 2003), but in subsequent versions of the auditory-visual distraction paradigm, the task was modified to classify digits vs. letters (Polo, Escera, Yago, Alho, Gual, & Grau, 2003), or to decide whether the present digit was bigger or smaller than 5 (SanMiguel, Escera, Erhard, Fehr, & Herrmann, in prep.).

The auditory-visual distraction paradigm was also tested to work with tasks using more complex visual stimuli and

decisions, such as classifying drawings into animate (animals) or inanimate (objects) categories (Gumenyuk, Korzyukov, Alho, Escera, & Näätänen, 2004), or in deciding whether the color of a figure (a face) was the same or different from that of its surrounding frame (Dominguez-Borràs, Trautmann, Fehr, Ehrard, & Herrmann, & Escera, submitted-a), or even whether two natural pictures presented simultaneously were equal or different (Dominguez-Borràs, Garcia-Garcia, & Escera, submitted-b). In all the tasks described thus far, the unexpected occurrence of a distracting sound – either deviant or novel – preceding the visual stimulus causes a delay in the subjects' responses (Figure 1), “distracting” current task performance. This distraction effect is larger in novel than in deviant trials (Escera et al., 1998, 2001), and for meaningful than for nonmeaningful novel sounds (Escera et al., 2003). As with the auditory-auditory distraction paradigm, the distraction effects can be also observed with tones deviating in other features than frequency, such as tone duration or intensity (Escera et al., 2002). In some studies, the response time increase in deviant trials was accompanied by a hit rate decrease caused by an error rate increase (Alho et al., 1997; Jääskeläinen et al., 1996; Escera et al., 1998, 2001, 2002).

The auditory-visual distraction paradigm has been shown to provide sizeable distracting effects in subjects over 8 years of age (Gumenyuk et al., 2001, 2004), in healthy elderly (Andrés, Parmentier, & Escera, 2006), and also in a range of clinical populations, including ADHD (Gumenyuk et al., 2005) and dyslectic (Corbera et al., in prep.) children as well as closed-head-injured patients (Polo, Newton, Rogers, Escera, & Butler, 2002), chronic alcoholics (Polo et al., 2003), and schizophrenics (Cortiñas, Corral, Garrido, Garolera, Pajares, & Escera, submitted). Moreover, these clinical studies allowed to demonstrate increased distractibility in most of patient groups (ADHD, dyslexia, schizophrenia), and even among normal aging persons (Andrés et al., 2006).

The Distraction Potential

Recording of ERPs during performance of the distraction paradigms described above allows investigation of the spatio-temporal dynamics of activation of the cerebral network underlying involuntary attention control. The typical ERP recorded in this scenario shows a complex morphology, both for the standard and the distracting trials, since it includes both auditory and visual responses (Figure 2a). However, a simple arithmetic computation, i.e., the subtraction of the responses elicited to standard trials from those elicited to the distracting ones, isolates the neuroelectric activation underlying behavioral distraction; for convenience, Escera and Corral (2003) termed this activation pattern the distraction potential (DP). The DP shows a characteristic triphasic shape, starting with a negative wave followed by a positive one, and ending with a final phase of a

more or less sustained negative potential (Figure 2b). Each of these waveforms provides a neurophysiological index of what are considered the three main processes involved in involuntary attention control (Escera et al., 2000):

- 1) the mechanism of attention capture, associated to the mismatch negativity (MMN) and/or to the N1 ERP,
- 2) the orientation of attention, associated with the P3a or novelty-P3, and
- 3) the reorientation of attention toward main task performance after a momentary distraction, associated with the so-called reorienting negativity (RON).

However, the precise relationship between these neurophysiological phenomena and the cognitive process attributed to them is not completely clear and is discussed below.

In order to capture attention, at least two cerebral mechanisms operate within the auditory modality (Näätänen, 1990). One mechanism is based on a neurophysiological reaction to transient increment/decrements in stimulus energy and has been associated with the auditory N1 (Näätänen & Picton, 1987), or at least with some of its components (Giard, Perrin, Echallier, Thévenet, Froment, & Pernier, 1994; Escera et al., 1998). The second mechanism relies on the dynamic modeling of regularity in the acoustic environment, and on the detection of any stimulus change that does not fit in with a neural trace of such regularity. This is, therefore a “change-detector” mechanism, which has been associated to the generation of MMN (Näätänen, 1990, 2007; Schröger, 2007; Winkler, 2007), and can best be isolated by using slightly different distracter stimuli with regard to the repetitive stimulation (see an extended discussion on this issue in Schröger & Wolff, 1998a).

The behavioral data obtained with the auditory-auditory (Rinne et al., 2006) and auditory-visual distraction paradigms support the existence of these two attention capture mechanisms. Specifically, the distracting effects observed with this later paradigm in novel and deviant trials display a distinct pattern. Indeed, whereas novel sounds cause a large delay in the response time to visual stimuli (about 25 ms), compared to standard trials, deviant sounds cause only a small response time increase (about 5 ms), but a noticeable increment in the number of erroneous classifications, as mentioned above. ERP recordings also show this differential effect, with a clear MMN generated to deviant distractors and a combined N1-enhancement/MMN elicited to novel distractors (Alho et al., 1998; Escera et al., 1998). A large body of evidence indicates that both the MMN and the N1 are generated within the planum temporale of the auditory cortex (Alho, 1995; Alho et al., 1998; Escera et al., 2000; Näätänen & Picton, 1987), with additional contributions from prefrontal regions (see Giard et al., 1994, for the N1; and Deouell, 2007, for the MMN).

The P3a waveform, generated with large amplitude to novel stimuli and therefore called novelty-P3 (see Simons, Graham, Miles, & Chen, 2001, for a discussion on whether the P3a and novelty-P3 can be considered the same ERP component), in the psychophysiological literature has been

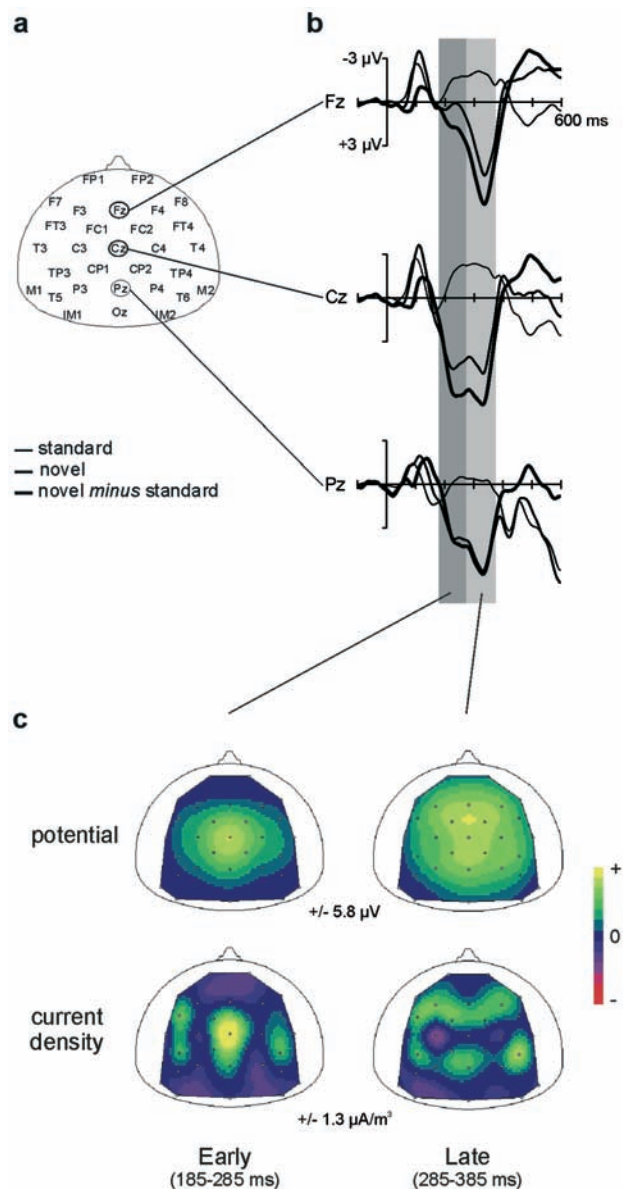


Figure 3. The novelty-P3. (a) The 30 electrode set used in the EEG recordings. (b) ERP at Fz, Cz, and Pz electrodes to standard and novel stimuli, and the corresponding difference waves. Gray shadows show the two phases of the novelty-P3, with latency ranges of 185–285 ms (dark gray) and 285–385 ms (light gray). (c) Scalp potential (SP) and current density (SCD) distributions of the two phases of the novelty-P3. The SCD analyses revealed positive currents over central, bilateral temporoparietal, and left frontotemporal areas during the early novelty-P3, and over superior parietal, bilateral temporoparietal, and frontal areas during the late novelty-P3. Adapted from Yago et al. (2003).

taken as a cerebral signature of the orienting response (Friedman, Cycowicz, & Gaeta, 2001; Knight, 1984; Squires, Squires, & Hillyard, 1975). Studies using the auditory-visual distraction paradigm have shown that novelty-P3 generation is accomplished in two consecutive phases,

each of them involving a different scalp distribution and a different sensitivity to attentional manipulations (Escera et al., 1998, 2001). The first novelty-P3 phase, with peak latency between 220 and 320 ms, has a centrally distributed topography and appears independent of attentional manipulations (Escera et al., 1998; SanMiguel, Corral, & Escera, in press; Domínguez-Borràs et al., in press; see, however, Domínguez-Borràs, Garcia-Garcia, & Escera, submitted-b). On the other hand, the second phase of the novelty-P3, occurring between 300 and 400 ms, has a right frontal scalp distribution and appears highly sensitive to attentional manipulations as it increases in amplitude, for instance, when subjects can monitor the sounds, i.e., in the auditory-visual paradigm, compared to a condition of passive listening (Escera et al., 1998; 2003; see the elaborated discussion below). The scalp-current density (SCD) analysis of the novelty-P3 recorded in the auditory-visual distraction paradigm has, in agreement with previous results (Herrmann & Knight, 2001), shown that novelty-P3 generation encompasses at least five different cerebral regions (Figure 3), engaged in clear spatiotemporal orchestration (Yago et al., 2003). This study suggested that the anterior cingulate cortex activated first (circa 160 ms), followed by the simultaneous activation of the bilateral temporoparietal and the left frontotemporal cortices (around 200 ms), finishing with activation of the superior parietal cortex and prefrontal regions (at 300 ms).

Equally as important as the flexibility to direct attention toward unexpected potentially relevant events outside the focus of attention is the ability to return attention back to original task performance after a momentary distraction. It has been proposed that this attentional process is associated with the generation of another ERP component recorded in distraction tasks, the so-called reorienting negativity (RON) (Escera et al., 2001; Schröger & Wolff, 1998b). In fact, Schröger and Wolff (1998b) in their recordings found a negative waveform, subsequent to P3a, only when their subjects carried out a task where the deviant stimuli acted as behavioral distractors, but not when the subjects were asked to actively discriminate these stimuli, or when they were instructed to completely ignore the auditory stimulation and to concentrate on an unrelated visual task. Moreover, Escera et al. (2001) argued that, to indicate the process of reorienting attention back toward main task performance, RON should be time-locked to target stimuli in the task and not to distracting ones. In their experiment using the auditory-visual distraction paradigm, the asynchrony between the distracter and the visual target was manipulated to 245 or 355 ms, under different conditions. Their results showed that RON peak latency was about 345 ms from visual target onset, regardless of distracter-target asynchrony (Figure 4). These results strongly suggest that RON generation reflects the process of returning attention back to primary task performance after a momentary distraction.

On the other hand, Escera et al. (2001) observed that RON actually had two different phases or subcomponents (Figure 4) which were dissociated on the basis of their dif-

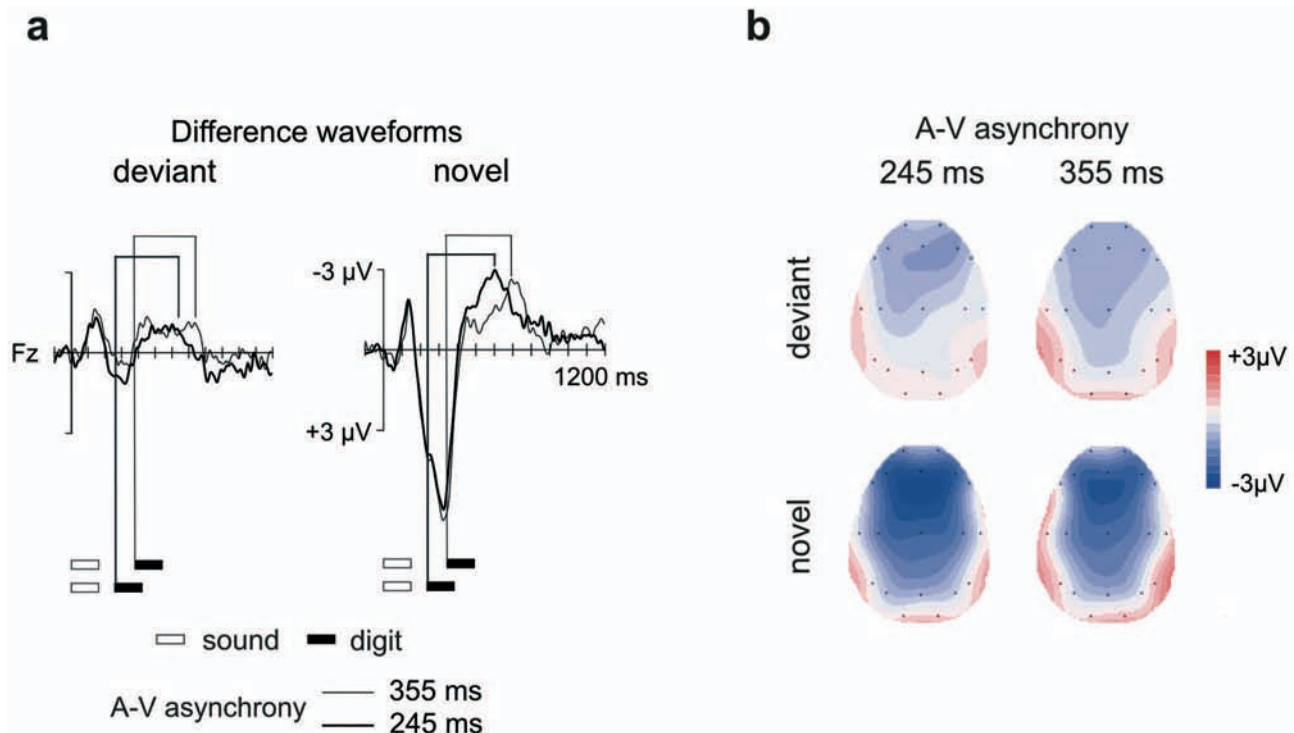


Figure 4. The reorienting negativity (RON) elicited in distracting trials, (a) as seen in difference waveforms at Fz. RON peaks at 345 ms from visual stimulus onset irrespective of distracter asynchrony. Notice, however, that RON might have two different subcomponents as suggested by the double-peaked negativity elicited in the deviant and novel trials of the 245 ms asynchrony (later confirmed by Munka & Berti, 2006). (b) The scalp distribution of RON obtained in deviant and novel trials for the two conditions of distracter-target asynchrony. Adapted from Escera et al. (2001).

ferent scalp distribution, and that the late subcomponent was the one time-locked to task-relevant aspects of stimulation, i.e., the visual stimulus. The existence of two RON subcomponents was confirmed in a recent study using the auditory-visual distraction paradigm by Munka and Berti (2006). These authors found that an early RON component was elicited when the discrimination task had a working memory component, i.e., consisting of making a semantic judgment on the visual stimuli (in fact, a classical odd/even classification). However, when the decision was based on a physical feature of the stimuli (size or color, in different experiments), only a late RON subcomponent could be observed.

What Is Being Distracted?

A critical issue to gaining insight into the neural mechanisms of involuntary attention toward unexpected deviant or novel sounds would be to establish what the cognitive process (or processes) is during visual task performance which are affected by the occurrence of the distracting sounds. Indeed, processing of distracting sounds could interfere with any of the several processes related to task per-

formance, such as identification of the visual stimulus, its classification, response selection, or response execution, to mention only a few. In an early study, Alho et al. (1997) observed that the visual N1 elicited to the visual target was attenuated when the preceding sound was a deviant one, suggesting that its occurrence attracted attention involuntarily to the auditory modality, leaving fewer resources available to analyze the visual target in extrastriate visual areas, where this component is generated (Mangun & Hillyard, 1991; Heinze et al., 1994). These data clearly suggest interference on visual stimulus identification.

Parmentier, Elford, Escera, Andrés, and SanMiguel (2008) went a step beyond by addressing the auditory-distracter/visual-target interaction. These authors argued that the interference of the distracting sound could occur either during visual stimulus identification or during response selection. To test these alternative suggestions, they devised an experiment in which visual stimulus discriminability was manipulated by adding a white noise mask to the visual target, or by making response selection more difficult as there were four possible response categories instead of the usual two. Their results showed that, whereas making both visual discrimination or response selection more difficult enlarged the time necessary to perform the task, the distracting effects of novel sounds were of equivalent size to

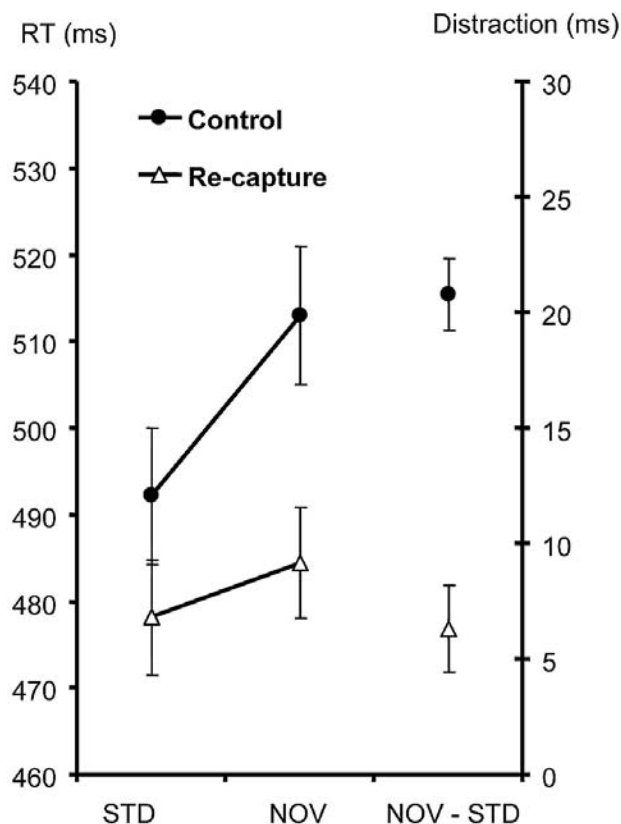


Figure 5. The cognitive locus of distraction. When a visual stimulus is quickly flashed within the interval between the distracting sound and the imperative visual stimulus, the distracting effects of the sound are abolished (adapted from Parmentier et al., 2008).

those observed in the respective control conditions (i.e., with no visual masking and with two response categories, respectively). The authors suggested that the distracting effect of the novel sounds should occur *before* the presentation of the imperative visual stimulus, and that the behavioral cost observed in the distracting trials would be due to the time necessary to move attention from the auditory modality, where it would get engaged by the novel sound, toward the visual modality upon the appearance of a visual target.

To confirm this hypothesis, in a subsequent experiment Parmentier and colleagues (Parmentier et al., 2008) quickly flashed (50 ms) a shrinking cross in the time period between the auditory, task-irrelevant stimulus and the visual target, in what they called a “re-capture” (of attention) condition. The results were clear cut: Whereas the effects of novel sounds on visual task discrimination in a control condition were as described previously, i.e., a significant response-time increase of about 25 ms, these distracting effects were abolished in the re-capture condition (Figure 5). These results demonstrated, according to the authors, that the unexpected task-irrelevant change in the auditory background engaged, and retained, attention in the auditory modality, and that the response time increase observed in the

distracting trials would reflect the time necessary to move attention back, from the auditory to the visual modality upon the occurrence of a fresh sensory event in the task-relevant modality, i.e., vision.

Although appealing, however, the results obtained by Parmentier et al. (2008) cannot fully disregard the possibility that the distraction effects observed with the auditory-visual distraction paradigm resulted from the time necessary to move attention between spatial locations instead of sensory modalities. In fact, it should be borne in mind that the visual stimuli are presented in a screen located in front of the subject’s head (usually, 100 cm), whereas the sounds are played binaurally through headphones. A preliminary study using loudspeakers placed beside the screen instead of headphones – but reproducing all remaining methodological details – failed to observe any distracting effects of novel sounds (Annett Schirmer, personal communication, January 2006). This negative result was replicated in a more recent and systematic study by Corral and Escera (in prep.), who varied systematically the location of the sounds presented in an auditory-visual distraction paradigm. In their experiments, the sequence of sounds (including both the standard and novel ones) was presented in separated conditions, binaurally through headphones or by means of loudspeakers located at 72° left, 18° left, 18° right, 72° right, and 0° from the computer screen on which the visual stimuli were being displayed. As observed in many previous experiments using the auditory-visual distraction paradigm, novel sounds occurring within the headphones sequence distracted subject’s performance, i.e., significantly increased response time. Interestingly, novel sounds occurring in any lateral location, except the 72° left one, also distracted subject’s performance in the visual task. However, as in the preliminary observation by Schirmer, the novel sounds occurring by the computer screen (0° location) failed to elicit any response time increase, compared to standard trials, in response to visual targets. This pattern of results challenges the interpretation of Parmentier et al. (2008) discussed above and strongly supports a role of spatial attention in explaining the distracting effects observed in the auditory-visual distraction paradigm.

Top-Down Modulation of Auditory Distraction

A major milestone in MMN theory is that the underlying process and the associated neural response is automatic, i.e., does not depend on the direction of attention (Näätänen, Paavilainen, Rinne, & Alho, 2007). Although this notion has been challenged by several empirical papers and has been object of an intense debate (see Sussman, 2007, for a comprehensive discussion), it is widely accepted that change detection in the auditory modality can be considered attention-independent. Nevertheless, it is a common

experience that the effects of an unexpected novel (or rare) sound in everyday life depends to a large extent on the ongoing activities: In general, highly demanding activities prevent distraction, whereas distractibility is enhanced during nonmotivating or nondemanding tasks. Experimental support for the common observation that distraction depends on top-down factors comes from studies of visual attention. These studies have shown, for instance, that when the location of a subsequent irrelevant stimulus is known beforehand, subjects could “block” that spatial location in a way that the ability of a distracter to attract attention involuntarily disappeared (Atchely, Kramer, & Hollstrom, 2000; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Yantis & Egeth, 1999; Yantis & Jonides, 1990). These and related observations led to the proposal that attention capture is not entirely determined by distracter properties, but rather by the *relationship* of these properties with those of the relevant stimuli (Folk et al., 1992). This “contingent-orienting” view of involuntary attention postulates, therefore, that the current “cognitive set” determines the attentional configuration in a top-down fashion, and that the occurrence of a distracter in the sensory environment will capture attention automatically, in a bottom-up manner, inasmuch as it fits with the attentional configuration (Pashler, Johnston, & Ruthruff, 2001). According to this theory, the occurrence of deviant, or novel, sounds in the distraction paradigms reviewed above should have an impact on subject’s performance and related brain responses, depending on the task assigned to them.

In fact, these “contingent-orienting” effects have been observed in the distraction paradigms described above, suggesting that they provide a suitable framework to study the neural mechanisms subserving the interaction between the top-down and bottom-up forms of attention control. In their seminal paper, Escera et al. (1998) already observed that, compared to a passive condition in which the subjects were instructed to read a book and to ignore the auditory sequence, the same novel sounds in the exactly same auditory sequence embedded in an auditory-visual distraction paradigm elicited a novelty-P3 of a much larger second phase, while the early one remained unaffected, suggesting a top-down modulation of the novelty-P3. A similar effect was further suggested by Escera et al. (2003), who found that meaningful novel distracters led to larger novelty-P3, compared to nonmeaningful ones, only when they were contingent to, i.e., occurred in a temporal relationship with, the visual task-relevant stimuli.

Moreover, in a study by Berti and Schröger (2003), using the auditory-auditory distraction paradigm, the distraction effects of deviant tones were largely reduced when the subjects performed a task that had a working memory component, i.e., withholding the response to the present stimulus until the subsequent trial (i.e., a 1-back task). These behavioral results were accompanied by an attenuation of the P3a and RON, whereas the MMN remained the same in the working memory and the corresponding control conditions. These results, involving

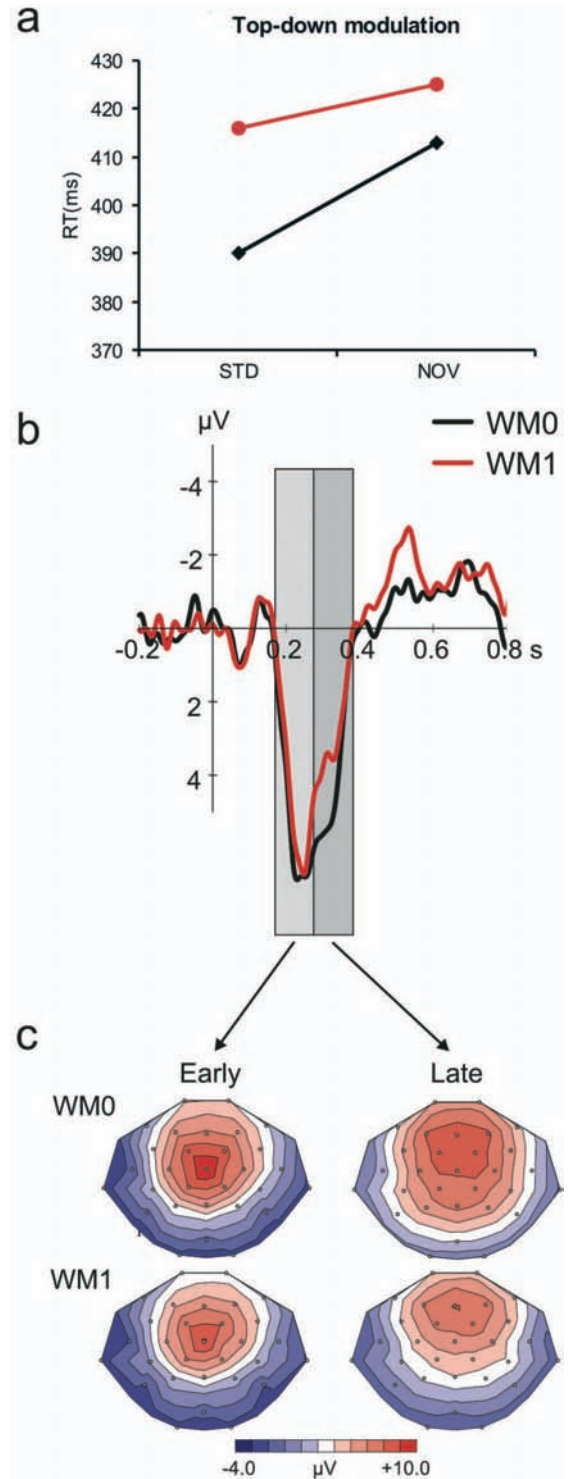


Figure 6. The top-down modulation of auditory distraction. When the visual task is made more difficult, for instance by imposing a load into working memory, involuntary attention toward distracting sounds is attenuated. This attenuation appears as a reduction in the behavioral distracting effects of the distracting sounds (a), and also as an attenuation of the late subcomponent of the novelty-P3 (b), also observed in the scalp-distribution maps (c) (adapted from SanMiguel et al., in press).

working memory manipulation, have recently been confirmed in a study using the auditory-visual distraction paradigm (SanMiguel, Corral, & Escera, in press). There, subjects were instructed to compare, in one condition involving a working memory load, the left-most digit of a two-digit number with the one of the same position displayed in the previous trial. The control condition was to decide whether the two digits were the same or different. As in the Berti and Schröger study, SanMiguel et al. (in press) observed a reduced distraction under working memory load and a reduced late-phase of novelty-P3 (Figure 6), while the early novelty-P3 and the N1-enhancement/MMN remained unaffected. Interestingly, and in contrast to Berti and Schröger's observations, RON was enhanced under the working memory load condition (SanMiguel et al., in press). Nevertheless, working memory load manipulation might result also in an increase of the distraction effects by deviant tones, as shown using the auditory-auditory distraction paradigm (Muller-Gass & Schröger, 2007). As discussed by these authors, the interaction between working memory and involuntary attention might depend on the channel separation between the distracting and target features of the stimuli (Lavie, 2005).

Another way of influencing involuntary attention through top-down factors would be by making the occurrence of the distracting sounds predictable. Such a scenario is similar to that used in the seminal experiments in the visual modality that lead to the formulation of the "contingent-orienting" view of involuntary attention outlined above. This was the rationale of an experiment by Sussman, Winkler, and Schröger (2003), who presented a visual cue preceding every sound of an auditory-auditory distraction paradigm. In a predictable condition, the visual stimuli indicated the pitch of the tone; in the unpredictable, the visual stimuli were randomly paired with the sounds, but did not provide any information on their pitch. Deviant tones occurring in the unpredictable condition elicited clear behavioral and a full "distraction potential." However, deviant tones in the predictable series failed to enlarge response time and also elicited an ERP that had comparable MMN to that observed in the unpredictable condition, but that clearly lacked the P3a and RON components (see also Wetzel & Schröger, 2007a, for similar results in children). Nevertheless, implicit predictability, i.e., sequences with regularly occurring standard and deviant tones seems not to be sufficient to prevent from behavioral and electrophysiological signs distraction (Jankowiak & Berti, 2007).

Still another particular circumstance in which top-down modulation is expected to exert a large influence on stimulus-driven brain responses is under emotional activation. A large body of evidence has shown that emotional stimuli have a privileged position in the environment, eliciting stronger and faster attention capture than nonemotional stimuli (Öhman, Flykt, & Esteves, 2001; Richards & Blanchette, 2004). Similarly, emotional con-

text has been reported to enhance the processing of concomitant sensory inputs, as indexed for instance, by startle reflex potentiation (Stanley & Knight, 2004; Amrhein, Mühlberger, Pauli, & Wiedemann, 2004; Bradley, Codispoti, & Lang, 2006) or sensory gating suppression (Yamashita, Okamoto, Morinobu, Yamawaki, & Kähkönen, 2004). This results in adaptive and evolutionary advantages: The consequences of reacting slowly to emotionally salient information could be more dramatic than the consequences of a similar reaction to neutral events. In the recent study mentioned above, Domínguez-Borràs et al. (in press) asked their subjects to decide whether the two pictures on the screen, arranged in an auditory-visual distraction sequence, were similar or different. Half of the pictures were of neutral emotional content, whereas the other half displayed affective images of a negative emotional valence, such as mutilations or destruction. Results were remarkable: The effects of novel sounds on visual-task performance and brain responses were magnified when the visual stimuli were of a negative emotional valence, i.e., their distracting effects were larger – and the late novelty-P3 was also enlarged, compared to the neutral condition.

Furthermore, a subsequent study using improved experimental design, Domínguez-Borràs et al. (submitted-b) replicated a similar increased distractibility under negative emotional load. In this case, however, the emotional context effects on novelty processing were already observable at the stage of the early novelty-P3. This contrasts with the previous studies showing top-down modulation on the late novelty-P3 (Domínguez-Borràs et al., in press; Escera et al., 1998; SanMiguel et al., 2008), but might be explained by the central role emotions play in regulating behavior. In fact, a related study by Domínguez-Borràs et al. (submitted-a), designed to measure brain activation with functional magnetic resonance imaging, yielded data that might help to explain the effects of emotion on the early novelty-P3. In their study using another variant of the visual task – a color decision on the color of a face and its surrounding frame (see section one) – subjects were largely distracted when the face portrayed a negative emotion (fear, anger) compared to neutral ones. Novel sounds, both in the neutral and negative conditions, activated the superior and medial temporal gyrus, as observed in previous studies (Downar, Crawley, Mikulis, & Davis, 2000; Opitz, Mecklinger, Friederici, von Cramon, 1999). However, a comparison of novelty activation in negative vs. neutral conditions resulted in increased activation in superior temporal gyrus in the negative condition, indicating gating of novelty processing in this cerebral region under emotional load. Interestingly, the brain regions that showed this emotional modulation are similar to those described as contributing to the early phase of the novelty-P3 (Alho et al., 1998; Yago et al., 2003), so that these findings provide support to the observation of enhanced early novelty-P3 by Domínguez-Borràs et al. (submitted-b).

Role of Mismatch Negativity and Novelty-P3 in Auditory Distraction

The studies reviewed in the preceding sections demonstrated that the occurrence of an unpredictable deviant or novel sound in the acoustic environment attracts attention involuntarily, and that this involuntary attention switch has specific behavioral consequences on current task-performance, i.e., impoverishes it, which is accompanied by a specific pattern of brain responses, the “distraction potential.” These studies used two versions of an auditory distraction paradigm, one using auditory and one using visual stimuli as targets, and in both cases have allowed to demonstrate that involuntary attention is contingent upon the demands of the task at hand, i.e., that the brain response to distracting sounds and their behavioral consequences are modulated by top-down factors. Although the two paradigms yield comparable results, i.e., deviant tones occurring in either of them result in delayed response time to subsequent targets, there are remarkable differences among them. First, the response time increase in the auditory-auditory distraction paradigm for deviant trials is about 50 ms, whereas it is only 10% thereof in the auditory-visual one, in both cases for a “standard” response time of circa 0.5 s. Second, the response time increase in the auditory-auditory distraction paradigm is always paralleled by a hit rate decrease, though this hit rate decrement is not always obtained with the auditory-visual distraction paradigm. And third, whereas there is a parallel increase of behavioral distraction and its accompanying electrophysiological signs in the auditory-auditory behavioral paradigm with increasing distracter salience (i.e., the deviant-standard difference; Berti et al., 2004; Jääskeläinen et al., 1999; Rinne et al., 2006), such a parallelism is not present in the auditory-visual distraction paradigm (Yago, Corral, & Escera, 2001b). Of course, a major difference between these two paradigms is that distracting information is carried by the same object or perceptual group in the auditory-auditory distraction paradigm, whereas distracting and target features are presented with a large channel separation, i.e., in different sensory modalities, in the auditory-visual distraction paradigm (see Escera et al., 2000, for further discussion). Nevertheless, these two paradigms provide a useful tool to investigate the mechanisms of involuntary attention and their particularities in children (Gumenyuk et al., 2001, 2004; Wetzel et al., 2004, 2006; Wetzel & Schröger, 2007a, b), aging (Andrés et al., 2006; Horváth, Czigler, Birkás, Winkler, & Gervai, in press; Mager, Falkenstein, Störmer, Brand, Müller-Spahn, & Bullinger, 2005) and clinical populations or drug conditions (Corbera, & Escera, in prep.; Cortiñas et al., 2008; Gumenyuk et al., 2005; Jääskeläinen et al., 1996, 1999; Knott et al., 2006; Polo et al., 2002, 2003).

As described above, a distracting sound elicits a distinct pattern of event-related brain responses, the DP, which is composed of three distinct waveforms (early negativity, positivity, and late sustained negativity), each of which re-

flect different ERP components. Early negativity reflects activation of the MMN generating process: a change-detector mechanism of rare sounds, or/and the activation of fresh neuronal elements upon the detection of new transient features of the stimulation; this later mechanism is associated with the auditory N1 or at least with some of its components (Näätänen & Picton, 1987; Escera et al 1998; Giard et al., 1994). Interestingly, both the MMN and the N1-enhancement recorded during distraction appear to be insensitive to top-down modulation, irrespective of the effects of the task at hand on distraction and brain responses subsequent to these two components. This suggests that transients/change detection is a fundamental property of the attentional system, one that operates automatically to prevent that any potential novel event in the acoustic environment to go unnoticed.

On the other hand, whereas the MMN and N1 mechanisms seem to operate automatically, the subsequent brain response, the P3a or novelty-P3 reflecting according to the most accepted view the orienting of attention toward unexpected deviant or novel sounds (Escera et al., 1998; 2000; Friedmann et al., 2001; Herrmann & Knight, 2001; Knight, 1984), is largely dependent on top-down factors. The studies reviewed above showed that the P3a elicited by deviant tones in the auditory-auditory distraction paradigm, as well as the novelty-P3 elicited by novel sounds in the auditory-visual distraction paradigm, can increase or reduce its amplitude, in parallel with effects of similar direction at behavioral level, i.e., enhanced or reduced distractibility, depending on the task at hand. This would support the P3a/novelty P3 as scalp signature of the involuntary orienting of attention; or, what is the same, one may take the occurrence of a distinct P3a as the probe that an effective orienting of attention toward distracting stimuli has taken place. This interpretation has been, however, recently challenged by a study of Rinne et al. (2006), who found that behavioral distraction increased as a function of intensity decrements in the absence of any P3a elicitation, contrasting with the results obtained for intensity increments, where behavioral distraction increments as a function on intensity increments were paralleled by a similar increase in P3a amplitude (see, however, Muller-Gass, Macdonald, Schröger, Sculthorpe, & Campbell, 2007, for P3a elicited to intensity decrements). These results call for a reconsideration of the role attributed to P3a generation in involuntary attention models. This is not the only case in which P3a/behavioral-distraction dissociations have been observed using the auditory distraction paradigms. Using the visual version, Munka and Berti (2006) observed the opposite phenomenon: generation of P3a in the absence of any signs of behavioral distraction. Similar results were also obtained by Yago et al. (2001b), who, in a study manipulating parametrically the deviant-standard frequency difference, found that the P3a (and also MMN and RON) increased linearly as a function of change magnitude, whereas no behavioral effects were observed except for the condition of 10% of change. These authors even reported a

facilitation effect for a condition with 5% of frequency change. A further dissociation was observed by Polo et al. (2003), where larger (late) novelty-P3s were observed in a group of chronic alcoholics, compared to matched controls, in the absence of any differences in behavioral distraction. As suggested by Rinne et al. (2006), one possible explanation for the lack of relationship between P3a elicitation and behavioral distractibility might have to do with the fact that two different brain mechanisms control automatically for detecting rare events in the acoustic environment, as largely discussed above, and that P3a generation might not constitute a general index of attention switching, but one related to attention switch triggered solely by the N1 mechanism.

Although interesting, the proposal by Rinne et al. (2006) is seriously challenged by two recent studies using the auditory-auditory distraction paradigm. In these studies, behavioral distraction effects, accompanied by the corresponding distraction potential were obtained in conditions in which the N1 mechanism for attention capture hardly can have been activated. In one of these studies, subjects were to discriminate the duration (short, long) of a second tone of a pair of tones while ignoring their corresponding frequencies. The second tone was 26% higher in frequency in the standard trials, but this relationship was reversed in the deviant ones, and the particular frequencies of the pairs varied randomly from 600 to 1200 Hz in steps of 10 Hz (Schröger, Bendixen, Trujillo-Barreto, & Roeber, 2007). In another study of the same group, Bendixen, Roeber, and Schröger (2006) presented their participants with sequences of short and long tones arranged in random order with any of eight different frequency values. The frequencies values were, unnoticed to the participants, arranged with an internal regularity that dynamically changed along the course of the experiment. In both cases, the violation of the abstract rule governing the frequency relationship of the standard pairs (Schröger et al., 2007), or the implicit acoustic regularity of the auditory sequence (Bendixen et al., 2007), elicited clear behavioral distraction and a clear distraction potential, including P3a. Remarkably, the lack of any specific physical feature defining the deviant events in these studies would have hardly activated a transient detector mechanism associated to N1. Rather, the attention capture mechanism involved in these experiments is that related to the dynamic modeling of regularity in audition, associated to MMN generation (Bendixen et al., 2007; Schröger et al., 2007; Winkler, 2007), suggesting that P3a elicitation and its association to behavioral distraction is independent of the N1 mechanism.

In summary, the studies reviewed support the role of the MMN generating process in drawing attention toward unexpected violations of the implicit regularity of the acoustic scene. Such a process would operate automatically, i.e., unaffected by top-down factors, and would complement another mechanism for attention capture, that related to energy transient detection, associated to N1 generation. In contrast with the most extended view on the P3a, however, it is proposed that, rather than reflecting orientation of atten-

tion per se, the P3a/novelty-P3 signifies the evaluation of the contextual novelty of unexpected sounds. Furthermore, it reflects the reconfiguration of a cerebral network involved in updating task set information for goal-directed action selection (Barceló, Escera, Corral, & Periañez, 2006).

Acknowledgments

This work was supported by grants from the Spanish Ministry of Education and Science (SEJ2006-00496/PSIC; Consolider-Ingenio 2010-CSD-2007-00012) and the Generalitat de Catalunya (SGR2005-00953).

References

- Alho, K. (1995). Cerebral generators of mismatch negativity (MMN), and its magnetic counterpart (MMNm), elicited by sound changes. *Ear and Hearing, 16*, 38–51.
- Alho, K., Escera, C., Díaz, R., Yago, E., & Serra, J.M. (1997). Effects of involuntary auditory attention on visual task performance and brain activity. *NeuroReport, 8*, 3233–3237.
- Alho, K., Winkler, I., Escera, C., Huottilainen, M., Virtanen, J., Jääskeläinen, I. et al. (1998). Processing of novel sounds and frequency changes in the human auditory cortex: Magnetoencephalographic recordings. *Psychophysiology, 35*, 211–224.
- Amrhein, C., Mühlberger, A., Pauli, P., & Wiedemann, G. (2004). Modulation of event-related brain potentials during affective picture processing: A complement to startle reflex and skin conductance response? *International Journal of Psychophysiology, 54*, 231–240.
- Andrés, P., Parmentier, F.B.R., & Escera, C. (2006). The effect of age on the involuntary capture of attention by irrelevant sounds: A test of the frontal hypothesis of aging. *Neuropsychologia, 44*, 2564–2568.
- Atchely, P., Kramer, A.F., & Hollstrom, A.P. (2000). Contingent capture for onsets and offsets: Attentional set for perceptual transients. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 596–606.
- Barceló, F., Escera, C., Corral, M.J., & Periañez, J.A. (2006). Task switching and novelty processing activate a common neural network for cognitive control. *Journal of Cognitive Neuroscience, 18*, 17324–1738.
- Bendixen, A., Roeber, U., & Schröger, E. (2006). Regularity extraction and application in dynamic auditory stimulus sequences. *Journal of Cognitive Neuroscience, 19*, 1664–1677.
- Berti, S., Roeber, U., & Schröger, E. (2004). Bottom-up influences on working memory: Behavioral and electrophysiological distraction varies with distractor strength. *Experimental Psychology, 51*, 249–257.
- Berti, S., & Schröger, E. (2003). Working memory controls involuntary attention switching: Evidence from an auditory distraction paradigm. *European Journal of Neuroscience, 17*, 1119–1122.
- Bradley, M.M., Codispoti, M., & Lang, P.J. (2006). A multi-process account of startle modulation during affective perception. *Psychophysiology, 43*, 486–497.

- Corbera, S., & Escera, C. (in prep.). Increased distractibility in developmental dyslexia as revealed by behavioral and event-related brain potential measures.
- Corral, M.J., & Escera, C. (in prep.). Effects of sound location on visual task performance and electrophysiological measures of distraction.
- Cortiñas, M., Corral, M.J., Garrido, G., Garolera, M., Pajares, M., & Escera, C. (submitted). Reduced novelty-P3 associated to increased behavioral distractibility in schizophrenia.
- Deouell, L.Y. (2007). The frontal generator of the mismatch negativity revisited. *Journal of Psychophysiology*, *21*, 188–203.
- Domínguez-Borràs, J., Trautmann, S., Fehr, T., Ehrard, P., & Herrmann, M., & Escera, C. (submitted-a). Gating of auditory novelty processing by emotional context in superior temporal gyrus.
- Domínguez-Borràs, J., Garcia-Garcia, M., & Escera, C. (submitted-b). Emotional context enhances auditory novelty processing: Behavioral and electrophysiological evidence.
- Domínguez-Borràs, J., Garcia-Garcia, M., & Escera, C. (in press). Negative emotional processing enhances auditory novelty processing. *Neuroreport*.
- Downar, J., Crawley, A.P., Mikulis, D.J., & Davis, K.D. (2000). A multimodal cortical network for the detection of changes in the sensory environment. *Nature Neuroscience*, *3*, 277–283.
- Escera, C., Alho, K., Schröger, E., & Winkler, I. (2000). Involuntary attention and distractibility as evaluated with event-related brain potentials. *Audiology & Neuro-Otology*, *5*, 151–166.
- Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention to acoustic novelty and change. *Journal of Cognitive Neuroscience*, *10*, 590–604.
- Escera, C., & Corral, M.J. (2003). The distraction potential (DP), an electrophysiological tracer of involuntary attention control and its dysfunction. In I. Reinvang, M.W. Greenlee, & M. Herrmann (Eds.), *The cognitive neuroscience of individual differences* (pp. 63–76). Oldenburg: Bibliotheks- und Informationssystem der Universität Oldenburg.
- Escera, C., Corral, M.J., & Yago, E. (2002). An electrophysiological and behavioral investigation of involuntary attention toward auditory frequency, duration and intensity changes. *Cognitive Brain Research*, *14*, 325–332.
- Escera, C., Yago, E., & Alho, K. (2001). Electrical responses reveal the temporal dynamics of brain events during involuntary attention switching. *European Journal of Neuroscience*, *14*, 877–883.
- Escera, C., Yago, E., Corral, M.J., Corbera, S., & Nuñez, M.I. (2003). Attention capture by auditory significant stimuli: semantic analysis follows attention switching. *European Journal of Neuroscience*, *18*, 2408–2412.
- Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.
- Folk, C.L., Remington, R.W., & Wright, J.H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset and color. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 317–329.
- Friedman, D., Cycowicz, Y.M., & Gaeta, H. (2001). The novelty P3: An event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neuroscience & Biobehavioral Reviews*, *25*, 355–373.
- Giard, M.H., Perrin, F., Echallier, J.F., Thévenet, M., Froment, J.C., & Pernier, J. (1994). Dissociation of temporal and frontal components in the auditory N1 wave: A scalp current density and dipole model analysis. *Electroencephalography and Clinical Neurophysiology*, *92*, 238–252.
- Gumenyuk, V., Korzyukov, O., Alho, K., Escera, C., Schröger, E., Ilmoniemi, R.J. et al. (2001). Brain activity indices of distractibility in healthy children of school age. *Neuroscience Letters*, *314*, 147–150.
- Gumenyuk, V., Korzyukov, O., Alho, K., Escera, C., & Näätänen, R. (2004). Effects of auditory distraction on electrophysiological brain activity and performance in children aged 8–14 years. *Psychophysiology*, *41*, 30–36.
- Gumenyuk, V., Korzyukov, O., Escera, C., Hämäläinen, M., Huottilainen, M., Häyrynen, T. et al. (2005). Electrophysiological evidence of enhanced distractibility in ADHD children. *Neuroscience Letters*, *374*, 212–217.
- Heinze, H.J., Mangun, G.R., Burchert, W., Hinrichs, H., Scholz, M., Münte, T.F. et al. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans. *Nature*, *372*, 543–546.
- Herrmann, C.S., & Knight, R.T. (2001). Mechanisms of human attention: Event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews*, *25*, 465–476.
- Horváth, J., Czigler, I., Birkás, E., Winkler, I., & Gervai, J. (in press). Age-related differences in distraction and reorientation in an auditory task. *Neurobiology of Aging*.
- Jääskeläinen, I., Alho, K., Escera, C., Winkler, I., Sillanauke, P., & Näätänen, R. (1996). Effects of ethanol and auditory distraction on forced choice reaction time. *Alcohol*, *13*, 153–156.
- Jääskeläinen, I., Schröger, E., & Näätänen, R. (1999). Electrophysiological indices of acute effects of ethanol on involuntary attention shifting. *Psychopharmacology*, *141*, 16–21.
- Jankowiak, S., & Berti, S. (2007). Behavioral and event-related potential distraction effects with regularly occurring auditory deviants. *Psychophysiology*, *44*, 79–85.
- Knight, R.T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology*, *59*, 9–20.
- Knott, V.J., Scherling, C.S., Blais, C.M., Camarda, J., Fisher, D.J., Millar, A. et al. (2006). Acute nicotine fails to alter event-related potential or behavioral performance indices of auditory distraction in cigarette smokers. *Nicotine and Tobacco Research*, *8*, 263–273.
- Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends in Cognitive Science*, *9*, 75–82.
- Mager, R., Falkenstein, M., Störmer, R., Brand, S., Müller-Spahn, F., & Bullinger, A.H. (2005). Auditory distraction in young and middle-aged adults: A behavioral and event-related potential study. *Journal of Neural Transmission*, *112*, 1165–1176.
- Mangun, G.R., & Hillyard, S.A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 1057–1074.
- Muller-Gass, A., & Schröger, E. (2007). Perceptual and cognitive task difficulty has differential effects on auditory distraction. *Brain Research*, *1136*, 169–177.
- Muller-Gass, A., Macdonald, M., Schröger, E., Sculthorpe, L., & Campbell, K. (2007). Evidence for the auditory P3a reflecting an automatic process: Elicitation during highly-focused continuous visual attention. *Brain Research*, *1170*, 71–78.
- Munka, L., Berti, S., 2006. Examining task-dependencies of dif-

- ferent attentional processes as reflected in the P3a and reorienting negativity component of the human event-related brain potential. *Neuroscience Letters*, 396, 177–181.
- Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences*, 13, 201–288.
- Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Erlbaum.
- Näätänen, R. (2007). The mismatch negativity: Where is the big fish? *Journal of Psychophysiology*, 21, 133–137.
- Näätänen, R., Gaillard, A.W.K., & Mäntysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychologica*, 42, 313–329.
- Näätänen, R., & Michie, P.T. (1979). Early selective attention effects on the evoked potential. A critical review and reinterpretation. *Biological Psychology*, 8, 81–136.
- Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: A review. *Clinical Neurophysiology*, 118, 2544–2590.
- Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and a analysis of the component structure. *Psychophysiology*, 24, 375–425.
- Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology General*, 130, 466–478.
- Opitz, B., Mecklinger, A., Friederici, A.D., von Cramon, D.Y. (1999). The functional neuroanatomy of novelty processing: Integrating ERP and fMRI results. *Cerebral Cortex*, 9, 379–391.
- Parmentier, F., Elford, G., Escera, C., Andrés, P., & SanMiguel, I. (2008). The cognitive locus of auditory distraction by acoustic novelty in the cross-modal oddball task. *Cognition*, 106, 408–432.
- Pashler, H., Johnston, J.C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology*, 52, 629–651.
- Polo, M.D., Newton, P., Rogers, D., Escera, C., & Butler, S.R. (2002). ERP and behavioral indices of long-term preattentive and attentive deficits after closed head injury. *Neuropsychologia*, 40, 2350–2359.
- Polo, M.D., Escera, C., Yago, E., Alho, K., Gual, A., & Grau, C. (2003). Electrophysiological evidence of abnormal activation of the cerebral network of involuntary attention in alcoholism. *Clinical Neurophysiology*, 114, 134–146.
- Richards, A., & Blanchette, I. (2004) Independent manipulation of emotion in an emotional stroop task using classical conditioning. *Emotion*, 4, 275–281.
- Rinne, T., Särkkä, A., Degerman, A., Schröger, E., Alho, K. (2006). Two separate mechanisms underlie auditory change detection and involuntary control of attention. *Brain Research*, 1077, 135–143.
- Roeber, U., Widmann, A., & Schröger, E. (2003). Auditory distraction by duration and location deviants: A behavioral and event-related potential study. *Cognitive Brain Research*, 17, 347–357.
- SanMiguel, I., Corral, M.J., & Escera, C. (in press). More working memory load equals less distraction: Behavioral and electrophysiological evidence from an auditory-visual distraction paradigm. *Journal of Cognitive Neuroscience*.
- SanMiguel, I., Escera, C., Erhard, P., Fehr, T., & Herrmann, M. (in prep.). Working memory load and distraction interaction: An fMRI investigation.
- Schröger, E. (1996). Neural mechanism for involuntary attention shifts to changes in auditory stimulation. *Journal of Cognitive Neuroscience*, 8, 527–539.
- Schröger, E. (2007). Mismatch negativity: A microphone into auditory memory. *Journal of Psychophysiology*, 21, 138–146.
- Schröger, E., Bendixen, A., Trujillo-Barreto, N.J., & Roeber, U. (2007). Processing of abstract rule violations in audition. *PLoS ONE* 2(11): e1131.doi:10.1371/journal.pone.0001131
- Schröger, E., Giard, M.-H., & Wolff, C. (2000). Auditory distraction: Event-related potential and behavioral indices. *Clinical Neurophysiology*, 111, 1450–1460.
- Schröger, E., & Wolff, C. (1998a). Behavioral and electrophysiological effects of task-irrelevant sound change: A new distraction paradigm. *Cognitive Brain Research*, 71, 71–87.
- Schröger, E., Wolff, C. (1998b). Attentional orienting and re-orienting is indicated by human event-related brain potentials. *NeuroReport*, 9, 3355–3358.
- Simons, R.F., Graham, F.K., Miles, M.A., & Chen, X. (2001). On the relationship of P3a and the novelty-P3. *Biological Psychology*, 56, 207–218.
- Squires, N.K., Squires, K.C., & Hillyard, S.A. (1975). Two varieties of long-latency positive waves by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, 38, 387–401.
- Stanley, J., & Knight, R.G. (2004) Emotional specificity of startle potentiation during the early stages of picture viewing. *Psychophysiology*, 41, 935–940.
- Sussman, E.S. (2007). A new view on the MMN and attention debate: The role of context in processing auditory events. *Journal of Psychophysiology*, 21, 164–175.
- Sussman, E., Winkler, I., & Schröger, E. (2003). Top-down control over involuntary attention switching in the auditory modality. *Psychonomic Bulletin and Review*, 10, 630–637.
- Wetzel, N., Berti, S., Widmann, A., & Schröger, E. (2004). Distraction and reorientation in children: A behavioral and ERP study. *Neuroreport*, 15, 1355–1358.
- Wetzel, N., & Schröger, E. (2007a). Cognitive control of involuntary attention and distraction in children and adolescents. *Brain Research*, 1155, 134–146.
- Wetzel, N., & Schröger, E. (2007b). Modulation of involuntary attention by the duration of novel and pitch deviant sounds in children and adolescents. *Biological Psychology*, 75, 24–31.
- Wetzel, N., Widmann, A., Berti, S., & Schröger, E. (2006). The development of involuntary and voluntary attention from childhood to adulthood: A combined behavioral and event-related potential study. *Clinical Neurophysiology*, 117, 2191–2203.
- Winkler, I. (2007). Interpreting the mismatch negativity. *Journal of Psychophysiology*, 21, 147–163.
- Yago, E., Escera, C., Alho, K., & Giard, M.H. (2001a). Cerebral mechanisms underlying orienting of attention toward auditory frequency changes. *NeuroReport*, 12, 2583–2587.
- Yago, E., Corral, M.J., & Escera, C. (2001b). Activation of the brain network of involuntary attention as a function of auditory frequency change. *NeuroReport*, 12, 4093–4097.
- Yago, E., Escera, C., Alho, K., Giard, M.H., & Serra-Grabulosa, J.M. (2003). Spatiotemporal dynamics of the auditory novelty-P3 event-related brain potential. *Cognitive Brain Research*, 16, 383–390.
- Yamashita, H., Okamoto, Y., Morinobu, S., Yamawaki, S., & Käh-

könen, S. (2005) Visual emotional stimuli modulation of auditory sensory gating studied by magnetic P50 suppression. *European Archives of Psychiatry and Clinical Neuroscience*, 255, 99–103.

Yantis, S., & Egeth, H.E. (1999). On the distinction between visual salience and stimulus-driven attention capture. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 661–676.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 121–134.

Accepted for publication: December 5, 2007

Carles Escera

Department of Psychiatry and Clinical Psychobiology
Faculty of Psychology
University of Barcelona
P. Vall d'Hebron 171
E-08035 Barcelona
Spain
Tel. +34 93 312-5048
Fax +34 93 402-1584
E-mail cescera@ub.edu