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The effects of attention and conscious state on the detection of gaps in long duration auditory stimuli

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HIGHLIGHTS

- A gap occurring in a long duration stimulus elicits a large N1 peaking at about 100 ms.
- The present study examined how attention to the gap and conscious state affected N1 and other ERP components.
- Attention in the waking state had minimal effect on N1. During sleep, an N1 could not be elicited by the gap during sleep, but the gap elicited a much larger P2.

ABSTRACT

Objective: To determine the extent to which the detection of a gap occurring in a long duration stimulus is affected by attention and conscious state.
Methods: The first experiment manipulated the extent to which active processing was required for the detection of a 20 ms gap in a 1.4 s duration pure tone stimulus. In a second experiment carried out during all-night sleep, a gap was presented in a 1.5 s noise segment having an intensity of 60 or 80 dB SPL.
Results: The gap-elicited N1 did not significantly vary with the extent of active processing during wakefulness. N1 was not elicited by the gap during NREM sleep and was much reduced during REM sleep. A large P2 and later N350 was however observed, varying directly in amplitude with the intensity of the noise segment.
Conclusions: The operations required for the detection of a physical gap function early in processing, at a pre-conscious level.
Significance: Attention had relatively little effect on the detection of a gap as indexed by the amplitude of N1. Detection of a gap also appears to be made during sleep, as indexed by a large amplitude P2.

1. Introduction

1.1. Detection of gaps

Most acoustic sounds vary over time. Temporal resolution (or acuity) is the ability to make discriminations of the changing sound, an ability thought to be critical for the perception of speech and the localisation of sound. Temporal resolution is often studied using gap detection methods. A subject might, for example, be asked to judge whether a silent period (or "gap") had occurred within a continuous or long duration auditory stimulus. The duration that a gap needs to be presented for it to be detected (the gap duration threshold) will vary depending on the intensity of the continuous stimulus in which it is embedded and whether it is embedded in noise or steady state pure tone bursts (Moore, 1997; Schneider and Hamstra, 1999; Zeng et al., 1999). There is general agreement that normal-hearing young adults can detect 3–5 ms gaps in moderately loud continuous white noise (Moore, 1997; He et al., 1999; Samelli and Schochat, 2008).

1.1.1. Gap-elicited ERPs

The behavioural determination of the gap duration threshold does require active participation of the subject. This may not be possible for infants, young children and the senile. Many laboratories therefore record event-related potentials (ERPs) following presentation of a gap or intensity change in a long duration stimulus. In waking young adults, such gap stimuli will elicit a negative deflection, often described as an N1, peaking at about 100 ms after the onset of the gap (offset of the stimulus). This is followed by a smaller amplitude positive deflection, P2, peaking at about 180–200 ms (Heinrich et al., 2004; Michalewski et al., 2005; Pratt

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et al., 2005, 2007; Lister et al., 2007; Dimitrijevic et al., 2009; Ross et al., 2010). There may also be an earlier very small amplitude positivity, P1, peaking at 50 ms, although this is equivocal (see Pratt et al., 2008). The amplitude of N1–P2 closely mimics behavioural detection accuracy (Pratt et al., 2005; Lister et al., 2007; Atcherson et al., 2009). As accuracy of detection increases, the amplitude of N1–P2 increases. N1 remains apparent for gap durations that exceed 5 ms, closely approximating gap detection threshold (Pratt et al., 2005).

1.1.2. Effects of attention

Clinical and applied studies usually record gap-elicited ERPs during so-called passive attention, in which patients do not actively attend to the auditory stimuli. It is thus critical that the absence of attention have minimal effect on the gap-elicited ERPs. If the gap-elicited ERPs are affected by nonsensory factors such as attention, and motivation, then whatever differences that are found across conditions or among groups could be attributed to factors other than the perceptual ability to detect the gap. Unfortunately, the effects of attention have not been studied extensively. Pratt et al. (2005) required subjects to actively detect gaps ranging in duration from 1 to 20 ms that occurred in continuous 65 dB HL (about 85–90 dB SPL) white noise stimuli. In a separate condition, subjects were asked to ignore the auditory stimuli while engaged in a reading task. The amplitude of N1–P2 did vary directly with the duration of the gap but did not significantly vary between attend and ignore conditions. Michalewski et al. (2005) also presented subjects with loud (90 dB SPL) continuous white noise in which gaps of varying duration were embedded. In one condition, subjects were asked to attend to the noise and actively signal their detection of the gap by button pressing. In another condition, subjects were asked to passively listen to the noise but were not required to actively detect the gap. Again, the N1–P2 that was elicited by the gap did not significantly vary between active and passive conditions, regardless of the duration of the gap.

The present study consists of two experiments that examine the extent to which gap detection is affected by the manipulation of attention and consciousness. Processing that does not require or benefit from attention and consciousness is said to reflect pre-attentive or pre-conscious operations. Such pre-conscious operations are generally carried out rapidly at an early level in processing. In the first experiment, the extent to which active, attentive processing was required to detect a gap was manipulated by varying processing demands. Subjects should not have been conscious of the gap when they were not attending to the stimulus containing the gap. It is, of course, methodologically difficult to determine the extent to which subjects are *not* attending a stimulus channel. For this reason, in a second experiment, stimuli were presented during an unconscious state, natural sleep.

1.1.3. Continuous and discrete stimuli

Many studies embed the gap in a continuous stimulus. The presentation of continuous sound can be problematic in the sleep laboratory, often resulting in arousals or awakenings during sleep. Moreover, the adverse effects of the several hour continuous exposure to even a moderately intense sound is a serious ethical issue. For this reason, discrete, relatively long-duration stimuli were employed in the present study. Li et al. (2005) recorded ERPs to 3 s noise stimuli, introducing a gap after 1500 ms. The long duration stimulus elicited a negative sustained potential (SP) (Picton et al., 1978) prior to the onset of the gap, the gap eliciting the usual N1–P2 potential. Pratt et al. (2007) have compared the effects of introducing a gap in discrete and continuous stimuli. They noted that a robust N1 was elicited by gaps occurring in discrete stimuli but it was attenuated relative to that observed when gaps occurred in a continuous stimulus. The use of a discrete, long duration stimulus has a secondary benefit. The reduced N1 following presentation of a gap embedded in a discrete stimulus is consistent with the fact that these gaps are more difficult to perceive than when embedded in a continuous stimulus. Attention may especially benefit the discriminability of such difficult-to-perceive signals (Näätänen, 1992; Muller-Gass et al., 2006).

A further advantage of the use of discrete long-duration stimuli is that when subjects are asked to detect an embedded gap, evidence of active, attentive processing is provided by the presence of a negative slow wave, the contingent negative variation or CNV (see Campbell et al., 2009 for details of the CNV results) that develops following the onset of a stimulus (the onset of the long duration tone in this study) and prior to the onset of a subsequent possible target (the gap, in this study). The CNV is thought to reflect active expectation of the target stimulus and motor preparation to respond to it. On the other hand, when active processing is withdrawn (i.e., when the auditory stimuli are processed passively), only the stimulus-related SP should be apparent.

1.1.4. Experiment 1. The effects of active processing on the detection of gaps occurring in long-duration stimuli

In the present study, the effects of the manipulation of active processing on the gap-elicited ERP were compared both between and within conditions. In an attend condition, subjects were asked to actively attend to a long duration low-pitched stimulus in order to detect a possible embedded gap. The ERP elicited by the gap was then compared to that elicited in an ignore condition. In this condition, detection of the gap could only occur as a result of passive processing. The attend and ignore conditions were designed to test the replicability of the previous Pratt et al. and Michalewski studies, but when a gap was embedded in a discrete stimulus. A problem with the comparison of the effects of attention between conditions (e.g., attend vs. ignore) is that factors other than attention, perhaps differential arousal or motivation, may also vary between conditions and thus act as a confound (Näätänen, 1992). This confound is controlled by varying attention within a condition. Thus, within the attend condition, the duration that active attention needed to be maintained was manipulated. This was accomplished by presenting subjects with two physically distinct stimuli, either a low- or high-pitched discrete tone both of which might or might not have contained a gap, within the same condition. The "relevant" low-pitched tone informed that further processing was relevant in order to detect a possible gap. The "irrelevant" high-pitched tone informed the subject that further processing was irrelevant, because a response was not required even if the stimulus contained a gap. Presumably, active processing of the irrelevant stimulus could be withdrawn rapidly upon extraction of its pitch. Thus, the gap could only be detected as a result of passive processing.

2. Methods

2.1. Subjects

Ten healthy young adults (3 men, 7 women) aged 19–24 years (Mean = 20.3 years) volunteered to participate in this study. None reported a history of neurological or psychiatric disorders. All reported normal hearing. This was subsequently verified using standard audiometric procedures for 500, 1000 and 2000 Hz pure tones. Written informed consent was obtained prior to the study and an honourarium was offered as compensation. This study was conducted following the Canadian Tri-Council (Natural, Health, and Social Sciences) ethical guidelines.