

EVENT-RELATED POTENTIAL MEASURES OF SLEEP DISTURBANCE BY OBTRUSIVE ACOUSTIC STIMULI

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1. AWARENESS OF AUDITORY INPUT

1.1 Active attention.

R. Näätänen, a prominent Finnish cognitive neuroscientist, has developed an elaborate model to explain how an individual becomes conscious of an acoustic sound (Näätänen, 1992). In the waking state, this usually requires active attention to the auditory source. The brain's attentional system largely inhibits the processing and consciousness of that which is not attended. Näätänen's model does provide two routes through which otherwise unattended acoustic input can however intrude into consciousness. In both routes, highly relevant auditory stimuli may cause awareness through passive attentional mechanisms.

1.2 Passive attention.

The first route involves the "transient feature detector system". All auditory input enters this system, whether attended or not. This system is, as its name implies, short-lasting and involved in basic feature detection of the auditory stimulus. The output of this system varies with the obtrusiveness of the stimulus. If the output reaches a certain, critical level, an interrupt is sent to the central executive (responsible for the allocation of attentional resources). This will result in an automatic switch of attention away from the task at hand and toward the obtrusive auditory stimulus, allowing the individual to become conscious of it. This is what is meant by "distraction".

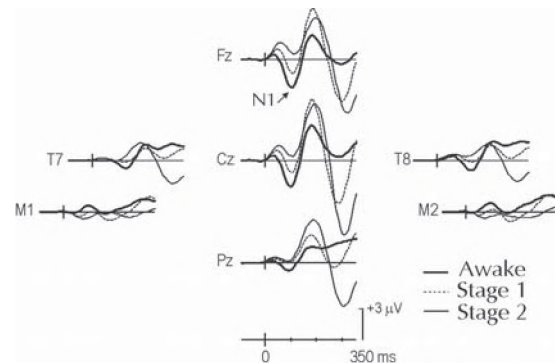
The second route involves the "change detector" system. Auditory stimuli that are not otherwise obtrusive can also result in a switch of attention, but only if they signal a change from the immediate acoustic past. It is assumed that auditory stimulus input is stored in a very brief duration echoic memory. If subsequent input matches this representation, further processing ceases and ongoing cognitive activity will not be disturbed. But, if the new input fails to match the representation, "change" is detected. If the extent of change is large enough, an interrupt will again be sent to the central executive and attention will be switched to the auditory channel.

2. EVENT-RELATED POTENTIALS

2.1 Waking auditory ERPs.

Measuring the extent of processing of unattended stimulus input presents many problems. Näätänen records the brain's minute response to the auditory stimuli, called the event-related potentials or "ERPs". ERPs allow the researcher to monitor the processing of auditory input even when the subject is not conscious that a stimulus had in fact been presented (Muller-Gass & Campbell (2002)

An auditory stimulus will elicit a series of long latency ERPs. In the figure below, a moderate intensity (80 dB SPL) brief auditory stimulus was presented every 1.5 s. This elicits a series of characteristic positive- and negative-going ERPs. Prominent among these is a negative wave, N1. In the waking state, N1 occurs at about 100 ms and is maximum over fronto-central (Fz/Cz) regions of the scalp. N1 is elicited automatically, independent of the attention and consciousness. Näätänen suggests that the amplitude of N1 varies directly with the output of the transient feature detector system. A particularly obtrusive stimulus will result in a switch of attention. The actual switching of attention is thought to be reflected by a later positive wave, often labeled the "P3a". P3a peaks from 250 to 300 ms after stimulus onset and is maximum over central areas of the scalp. Current evidence suggests that N1 is generated in the auditory cortex whereas the switching of attention associated with P3a may be a function of the executive control system of frontal lobe.



Acoustic change elicits a slightly later negativity called the Mismatch Negativity (MMN), peaking from 120 to 250 ms depending on the extent of acoustic change. The MMN is also thought to occur relatively independently of attention. A very large change in the auditory stimulus will elicit a switch of attention, observed again by the later positive wave, the P3a.

3. SLEEP ERPs

3.1 Sleep physiology

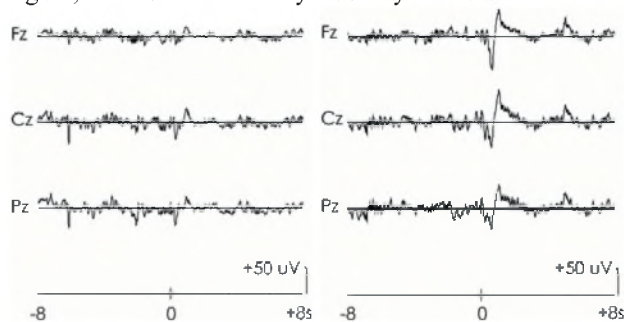
At sleep onset, consciousness (or “awareness”) of the external environment and internal mental state is gradually lost. This is why sleep is called an “unconscious” state. Unlike other unconscious states, sleep can be reversed either through natural awakenings or through particularly obtrusive external stimuli. Sleep is not unique. It consists of two major sub-divisions or “stages”, non-REM and REM sleep. Non-REM is further subdivided into stages, numbered 1 to 4, larger numbers corresponding to greater depth of sleep.

3.2 Loss of the waking ERPs.

In order to sleep, processing of external stimulus input must be inhibited. Nevertheless, highly relevant and obtrusive stimulus input must somehow be detected and if necessary, result in an awakening. Figure 1 indicates that activity of the transient detector system essentially ceases at sleep onset. N1 gradually declines in amplitude during the transition from a waking to a sleeping state (stage 1) and reaches baseline level during definitive stage 2 sleep (Campbell & Colrain, 2002). The MMN also gradually reaches baseline level during non-REM sleep. In the young adult, there is thus little evidence of consciousness of the auditory stimulus during non-REM sleep. During REM sleep, N1 returns to about 25% of its waking level. It is also possible to elicit P3-like ERPs (peaking from 300-400 ms) providing the stimulus is extremely obtrusive (it is loud and occurs extremely rarely, Cote et al., 2001) or if the stimulus is psychologically meaningful (perhaps the name of the subject). These late positivities, occurring from 250-400 ms following stimulus onset, may reflect a disturbance of the sleep state.

3.3 Sleep-Related ERPs: The K-Complex.

During non-REM sleep, even a highly obtrusive stimulus will usually fail to elicit the N1 or MMN potentials in young adults. It may however elicit the largest response known to occur in the human brain, the K-Complex (Bastien & Campbell, 1994). The K-Complex cannot be elicited in the waking state or in REM sleep. In the right portion of figure, a moderate intensity auditory stimulus elicits the K-



Complex during non-REM sleep. The K-Complex consists of a series of components, the most prominent of which is a

very large amplitude negative wave “N550”), peaking as it label suggests at about 550 ms after stimulus onset. Interestingly, identical stimulus parameters will sometimes elicit a K-Complex and sometimes will not (left-portion of figure).

In young adults, like the waking P3a, the K-Complex is most easily elicited by stimuli that occur very rarely, are very loud or very abrupt (Bastien & Campbell, 1994). There is some evidence that the subject’s own name can also elicit the K-Complex. The function of the K-Complex remains disputed. It has been suggested that it may serve a protective role, protecting sleep from unwanted disturbances. It may act as a secondary inhibitory system following failure of the inhibition of either the transient or change detector systems that normally occurs in non-REM sleep. Thus, the K-Complex may be elicited by highly relevant stimuli, yet they are not so relevant that the sleeper needs to awaken. Interestingly, obtrusive stimuli that fail to elicit the K-Complex may produce sleep fragmentation. These are brief arousals that do not lead to awakenings yet affect performance on many tasks the next day.

It has been well-established that the elderly have difficulty in falling asleep and once asleep, remaining asleep. Recent studies have indicated that the inhibition of processing that is apparent in younger adults within sleep may often fail in the elderly (Crowley & Colrain, 2004). The P2 (or perhaps P3a) component of the auditory ERP increases in amplitude in the elderly during non-REM sleep. At the same time, K-Complexes are very difficult to elicit and when they are elicited, their amplitude is much reduced.

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