MMN is a negative component resulting from the differ-
ence in event-related potential (ERP) waveforms elicited
by a standard and a deviant stimulus. It is usually studied
in the absence of attentional requirements. We compared
this measure of perceptual comparison in a non-task situ-
ation (three tones presented) with that obtained in a task
requiring focused attention and response to the third
tone. MMN (comparison of standard and deviant irrel-
evant tones) increased with focused attention to the third
(target) tone and frontal maxima shifted slightly pos-
teriorly. The succeeding P3 in the difference waveform
increased more posteriorly than frontally confirming con-
tinued differential processing of irrelevant stimuli under
active conditions. This demonstrates that not only attend-
ing to stimuli, but the active processing of irrelevant stim-
uli (vs passive perception) involves small changes in the
amount and distribution of neural activity.

Key words: Focused attention; Event-related potential
(ERP); Mismatch negativity (MMN); P3

Mismatch negativity (MMN) is altered by directing attention

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Introduction

Selective attention research is concerned with how
relevant and irrelevant information is separately
treated.[1] Research tends to have concentrated on the
uniqueness of relevant feature processing. Here we
concentrate on the processing of irrelevant features.
Stimuli may be irrelevant because the situation has no
requirements for focused attention (i.e. passive, diffuse
attention) or because attention is directed to another
stimulus (i.e. active, focused attention).

MMN is the difference between event-related
potentials (ERPs) following two stimuli automatically
elicited when one is unusual.[2] It is a negative compo-
nent occurring about 150–250 ms after the stimulus
and is claimed to represent a perceptual trace of the dif-
ference between stimuli.[1] We ask whether MMN eli-
cited in a passive situation changes when attention is
focused on another stimulus: a decrease might be
expected to result from an active resistance against dis-
traction, but an increase might result from the active
state of focusing attention, perhaps resulting from
active comparison of the range of stimuli available.

If the mismatch concerns the attended stimulus (i.e.,
processing negativity, PN) this can be larger than the
MMN derived from two non-attended stimuli.[3] From
this we would predict that MMN in passive/active con-
ditions would either show no change or decrease as
resources are directed to the target. However this PN/
MMN differential has not been found in other audi-
tory tasks.[4,5] Here raw data are presented which show
an increase in MMN amplitude with attention and
vector-normalized data to illustrate its topography.
Subsequent P3 data were analyzed to see whether
MMN changes had consequences for later-information
processing and earlier peaks are briefly described for
indications of pertinent precursor changes.

Materials and Methods

Healthy right-handed subjects with normal hearing,
aged 18–25 years (nine male, 16 female), were pre-
sented with blocks of 100 tones in a Bernoulli sequence
over headphones (0.8 kHz $p = 70$ %, 1.4 kHz $p = 15$%,
2.0 kHz $p = 15$% at 65 dBSL, rise/fall time 10 ms, dur-
ation 50 ms, interval 1.2–1.7 s). The first 2–3 blocks
were presented in a passive non-task situation (diffuse
attention). After ascertaining that the tones could be
distinguished, recording continued as an active dis-
crimination with focused attention on the 1.4 kHz tone
as target, requiring the finger to be lifted from an elec-
trical contact. Data for the target tone are not analysed
here.

Data were collected at 250 Hz for 972 ms relative to a
50 ms pretrigger baseline, after automatic rejection of
eye movement and muscle artifact detected by the ver-
tical EOG from above the right eye (20 ± 11% of trials
were rejected, 190 ± 50 and 33 ± 7 trials accepted for
standard and rare tones, respectively). Recordings
were made from an electrocap from the following sites
in the 10–20 system: Fp1, Fp2, F7, F3, Fz, F4, F8, T3,
C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2, referenced
to linked ears and Fpz and Oz as separate ground elec-
trodes, with an impedance of < 2 kΩ at all sites. Data
were recorded on a Siemens EEG 21 and 20 MHz
Compaq 386 pc and amplified by 12 K using a band
pass 0.3–70 Hz.

MMN was calculated separately for the passive
(MMNp) and active conditions (ERP after 1.4 kHz
2.0 kHz – ERP after 0.8 kHz). Topographic maps
were made using a linear interpolation (Crout algo-
rythm). Peaks were defined as the largest positive (P) or
negative (N) deflections in the time windows as fol-
lows: P1, 20–120ms; N1, 60–170ms; P2, 120–240ms;
N2 (MMN), 170–300ms; P3, 240–540ms. (These terms

follow the convention for stimulus-elicited ERPs and not that adopted in some subtraction wave studies where MMN is taken as 'N1'[16].

A MANOVA statistical analysis was performed on the raw and vector normalized data for quantitative and topographical evaluation, respectively, for two attentional conditions and 15 recording sites (excluding Fp and O sites) with repeated measures (see legend to Table 1). Post hoc Student's t-test were used to confirm the locus of the effect where the interaction showed that this varied topographically (Bonferroni correction, $\alpha < 1.0\%$).

Results

P1 peaks decreased from passive to active conditions at all sites, but maxima remained centroparietal (e.g., Pz, passive/active, mean 1.8/1.5 μv; Table 1). The decrease on the left was twice that in the midline and on the right (range 0.12–0.46 μv, 7–18% vs 40%, Fig. 1).

N1 maxima remained frontocentral. Only here were there increases from passive to active conditions by 0.2 (midline) to 0.4 μv (lateral), attaining a mean maximum of about –3 μv (i.e. 7–18% increase; Table 1, Fig. 1). At Pz negativity tended to decrease.

P2 maxima were parietal (mean + 2 μv). Increases from passive to active conditions of 0.4–0.6 μv were seen at most sites (Table 1) but small decreases were recorded over posterotemporal areas (Fig. 1).

MMN was maximal over frontocentral areas. It increased in active conditions at frontal, temporal and central sites (by 40–55% to – 4.8 μv at Cz: Fz and Pz, t – 2.7 to 3.0 $p < 0.01$), whereby the absolute maxima

shifted from Fz to Cz (Fig. 2, top left). The source of the significant condition × site interaction (Table 1) was not found in the selected, between-condition, post hoc comparisons and probably reflected the relative left vs right positive shift seen over temporal sites (Fig. 2, bottom left).

P3 amplitude changes with condition depended on site. They increased by a half at the parietal maximum, reaching 7.9 μv, but only by a third at frontocentral sites (Cz/Pz, t 2.7/4.3, $p = 0.014/0.000$). At lateral posterior sites they tended to increase by about 20% (T5 t + 2.1, $p = 0.05$), while at lateral frontal sites they decreased by a similar amount.

The P3 latency was the only latency measure to change significantly with condition: (there was a non-significant increase for P2). P3 latencies were longest at Pz (Fig. 2, right) and increased at most sites in the active condition, more consistently at posterior sites by about 6%.

Discussion

Stimulus-elicited P1 peaks usually show frontal maxima,[9,10] but here in the difference wave they occur posteriorly.[5] This could reflect polarity reversal of an anterior negative component, but in view of the enhanced left-sided decrease seen in the active condition which does not mirror other components, this seems unlikely.

Our N1 may relate to the 'early MMN' of Woods.[11] It responded differently to the N2 to changes in condition (local frontal increase vs parietal decrease), indirectly supporting the proposal that the early and late components reflect different generators[11] and that it is not simply an early precursor to the later N2/MMN.

Both P2 and MMN have two sources, one in the superior temporal plane of the auditory cortex and another more laterally in the temporal lobe.[12,13] The closeness and possible functional interdependence of these is indicated by the slight posterior topographic shift of the P2 which matches the slight shift of the N2 with focused attention away from posterior temporal sites.

A larger MMN was recorded for two irrelevant tones when attention was directed to a third tone. After these data had been collected, Näätänen's group reported results from an ingenious dichotic stimulus presentation.[14] They presented a different three-tone oddball simultaneously and rapidly to each ear. MMN in the unattended ear paralleled that in a passive presentation of the tones, while that in the attended ear was increased. Our results broadly support this finding but unlike these authors we would not attribute this directly to concurrent PN operations involving the target as we found that the maximum size of peaks in difference waves derived from the target tone were smaller (and later) than the MMN.[5]

Table 1. Summary of MANOVA for condition (diffuse/focused attention) × site interactions for 5 ERP peak amplitudes (MMN & P3 latency) in the deviant minus standard waveform

Peak data	Hotellings T2 test:			site-averaged tests:			epsilon	sig
	dF	F	p	dF	F	p		
P1 raw	14, 18	2.8	0.045	14,336	2.5	0.002	0.261	*
norm	14, 18	2.3	0.086	14,336	3.8	0.000	0.341	?
N1 raw	14, 18	2.3	0.081	14,336	3.5	0.000	0.483	?
norm	14, 18	2.9	0.042	14,336	3.6	0.000	0.365	*?
P2 raw	14, 18	10.2	0.000	14,336	3.9	0.000	0.367	**?
norm	14, 18	1.7	0.188	14,336	3.1	0.000	0.375	?
MMN								
raw	14, 18	8.7	0.000	14,336	8.0	0.000	0.410	***
norm	14, 18	5.5	0.004	14,336	7.4	0.000	0.444	**?
latency	14, 18	1.2	0.395	14,336	1.0	0.421	0.453	NS
P3 raw	14, 18	5.9	0.003	14,336	26.5	0.000	0.402	**?
norm	14, 18	6.6	0.002	14,336	15.7	0.000	0.423	**?
latency	14, 18	4.1	0.013	14,336	3.3	0.000	0.396	**

Norm = vector normalized data (mean of each component measure at each site was divided by the square root of the sum of the squared mean measures for the 15 recording sites).[7]
Hotellings test = for potential between measures differences.[8]
site-averaged tests = SPSSX test averaged across electrodes (repeated measures).
dF = degrees of freedom, p = statistical probability of test, sig = overall significance after correction for the number of degrees of freedom with the Greenhouse-Geisser epsilon factor ($*p < 0.05$, $**p < 0.01$, $***p < 0.001$, ? = Hotellings/averaged test conflict over decimal place for significance, NS = not significant).
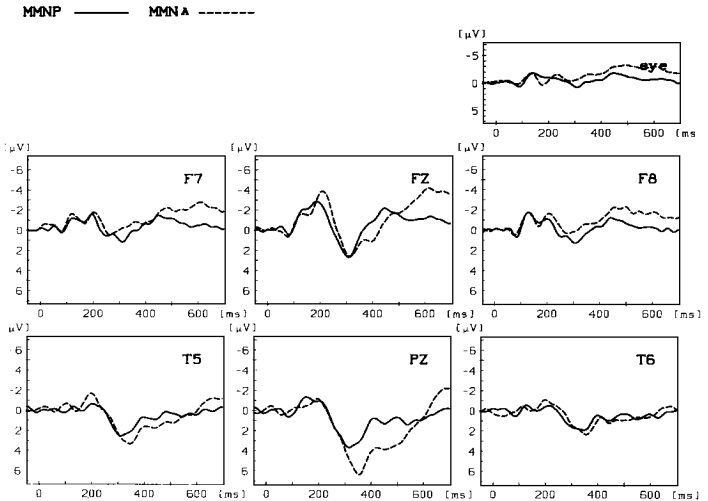
MMNP ———— MMN A -------

FIG. 1. Grand mean ERP subtraction waveforms (uV; ERP after 2.0 kHz, ERP after 0.8 kHz tones) are shown for the passive, diffuse attention (solid line, MMNP) and active focused attention condition (broken line, MMNA) where response to the 1.4 kHz tone was required, at selected anterior (F7, Fz, F8) and posterior recording sites (T5, Pz, T6) for 700 ms after tone presentation (insets show the EOG representations of eye movements).
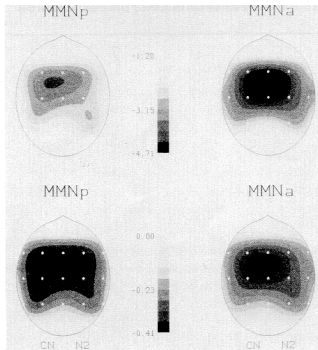
P3 LATENCY (ms)
in deviant-minus-standard waveform
in passive/active conditions
Sites F7-Fz-F8 / T3-Cz-T4 / T5-Pz-T6

(passive/active)

(L)	(R)	sd
305/ 324/	320/	(44-71)
337 341	316	
Cz		
333/ .336/ .	. 319/	(58-85)
349 343	347	
335/ 352/	350/	(53-77)
356 370	363	

FIG. 2. (Left) Topographic distribution of raw (upper) and normalized (lower) mean peak amplitudes for MMN (N2) in the deviant (2.0 kHz) minus standard (0.8 kHz) waveforms with anterior sites uppermost in each map: MMNp =MMN in passive condition; MMNa =MMN in active condition (target = 1.4 kHz tone). The two upper parts show raw amplitude data (MMNP and MMNA) and the two lower parts show the distribution according to normalized data (MMNP and MMNA). (Right) Topographic representation of mean P3 latencies (ms) in passive and active conditions from selected sites in the deviant minus standard waveforms, with standard deviation range on the right.

Perhaps the best explanation for an increase of MMN when attention is directed away from the stimuli concerned (here 0.8 and 2.0 kHz tones) derives from the observation of Näätänen,[9] that its amplitude increases as a function of the degree of deviance: thus deviance here is perceived to increase when attention is directed to another tone (here 1.4 kHz) by comparison with the passive situation when the third tone is equally irrelevant. This is apparently an active process.

Unsurprisingly the registration (updating[15]) of the stimulus difference by the P3 in the focused attention condition was slightly delayed and peak size increased. This was noticeable at posterior temporal sites, as previously reported,[14] but unlike that report, here there was no evidence of a rightward shift with attention.

Conclusions

Comparator processes concerning irrelevant stimuli incur more excitatory neural activity[16] when they occur in task than in non-task conditions. MMN topography did not show marked changes but frontocentral sources were more localized in the active condition. Precursor indicators of the effect of condition are limited to the immediately preceding positivity (P2). Succeeding increases in the difference-P3 (updating) were marked over parietal and posterior temporal regions.

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General Summary
We looked for signs that the brain processes tones differently in a situation where they are irrelevant (not those requiring response: focused attention) compared with when there is no task (all tones are irrelevant: diffuse attention). If an electroencephalogram (EEG) is recorded from the scalp after a tone, the average after many tones is an event-related potential waveform (ERP). When the ERP after a frequent tone is subtracted from that after another, rarer tone then a negative potential is seen after about 0.2 s; the mismatch negativity (MMN). This is a neural trace of activity representing the perceived difference between non-target tones. Here the MMN for non-target tones in an auditory task was larger and showed a more local distribution than the MMN to the same tones in a nontask situation. The following positive potential, related to the updating of traces also increased. The result shows that irrelevant stimuli can be actively processed and that this activation is localized over frontocentral cortical regions.