PROCESSING OF GLOBAL AND LOCAL STIMULI: AN ERP STUDY

EVENT-RELATED POTENTIALS IN GLOBAL-LOCAL PROCESSING: LATERALIZATION, PARALLEL PROCESSING AND THE EFFECT OF UNATTENDED VARIABILITY

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Abstract

An object in the visual field can be perceived as a whole and as the parts from which the whole is composed. Early investigations into whole-part processing led to the hypothesis that the global aspect, the whole, is processed before the local aspects, the parts. However, recent electrophysiological work shows that in the early stages of processing, the global and local levels of an object are processed in parallel. In addition, a processing asymmetry exists in that the right hemisphere is biased for global level processing whereas the left hemisphere is biased for local level processing. In an ERP study, I examined the lateralization and time-course of global-local processing in normal adult humans and found further evidence for lateralized, parallel processing of global-local stimuli. More importantly, I found that task demands affected the latencies at which lateralized differences between the two levels emerged: a condition in which interference from one level on the other was minimal showed very early, lateralized attentional effects (80 ms). In a relatively more demanding condition, lateralization of global and local processing was not evident until 200-350 ms. One possible explanation is that as the influence of distractors at the unattended level increases, resources in both hemispheres are engaged.

To corroborate these findings, I included conditions in which subjects were required to switch attention among levels and visual fields: Evidence for lateralization and parallel processing persisted. Moreover, the additional load placed on the system by the switching conditions was apparent at the N1 component and support for right hemisphere attention switching mechanisms was obtained.

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Global Precedence

Objects in the visual field are often regarded as having a multiple-level, hierarchical structure. For example, when one views a house, the outline or global form of the house is likely to be noticed first. Perception then appears to proceed to local features such as windows and doors that are embedded in the global form. This process can continue to even finer local details such as brickwork and other ornamentation. During this process, the representation of the levels is maintained so that the object is perceived finally in its entirety. Thus, apprehension of an object appears to involve processing of various levels and then integration of those levels to result in a complete percept. The mechanisms by which this processing is achieved have been under considerable scrutiny in recent years.

The Gestalt psychologists proposed that the visual system processed the global form of an object before processing the local components. Moreover, they proposed that perception of the whole object was different from perception of the parts; the global form could alter the perception of the local components (Koffka, 1935). Since that time, several interesting features of global/local processing have emerged. In this paper, I examine hemispheric lateralization of global and local processing mechanisms and the order in which the levels are processed. As well, I examine the impact of task difficulty and distractor variability on lateralization: these factors appear to influence the allocation of spatial attention to the two levels.

Much of the groundwork in the study of global and local processing was laid by behavioural studies that examined reaction time (RT) and interference effects. To simulate the hierarchy inherent in natural objects, Navon (1977) created hierarchical figures in which local elements were spatially arranged into a global form (Figure 1). These stimuli allowed controlled study of global/local processing. Typically, a subject was presented with a simulated hierarchical figure and the time required to identify a target at the global versus the local level was measured. Because subjects were not advised of the level at which a target would appear, this constituted a divided attention paradigm. Navon found that mean reaction times (RT) to the global level of the stimulus were significantly faster than mean RTs to the local level. Navon interpreted this result as a speed of processing advantage for the global level.

Navon also found that the global level interfered with perception of the local level but that the reverse was not the case. Subjects identified a target letter that appeared at one of the levels. At the unattended level, a letter appeared that was either the same as the target letter (consistent distractor) or different from the target letter (inconsistent distractor). Navon found that when the letter at the unattended local level was inconsistent with the letter at the attended global level, subjects took the same amount of time to respond to the global target as when the local letter was consistent with the letter at the global level. However, responses to a local target were slowed when the global letter was inconsistent with the local target. That is, the global level interfered with processing at the local level. However, inconsistent letters at the local level did not interfere with processing the global level: interference was unidirectional.

In conjunction with the speed of processing advantage for the global level, unidirectional interference effects led Navon to propose that the global level dominated in the perception of objects. That is, features at the global level of an object were available earlier in the percept than local features. Indeed, he proposed that perception of objects invariably began with global analysis and progressed to local analysis only if necessary: global processing was mandatory for perception whereas local processing was not. Navon coined the term *global precedence* to describe the phenomenon. In a subsequent paper, Navon (1981) tempered these statements by stating that the global precedence phenomenon was only intended to describe the notion that global features are perceptually available earlier in time than the local features. It was not intended to imply that the global level was processed to completion before local processing could ensue.

The notion of global precedence was consistent with the Gestalt view that processing was accomplished in a manner in which identification of the global form facilitated later analysis of local features. However, Navon (1977, 1981) himself noted that the global precedence that he observed might have been a function of stimulus characteristics such as peripheral presentation or relative size. Indeed, Grice, Canham and Borroughs (1983) produced evidence that global precedence was not a necessary condition in the perception of hierarchical objects. They controlled fixation so that the local level stimuli were accessible by the foveal (high-acuity) region of the retina and found no significant RT differences for global versus local stimuli. However, when stimuli were presented rapidly and unpredictably to the periphery, making the local stimuli less clear, global precedence was observed. They concluded that if perception of the local level was degraded in any way, global precedence resulted. However, if the local and global levels were perceptually discriminable to the same extent, the global level did not always take precedence over the local level.

Other factors that called into question the inevitability of global precedence were examined. For example, several groups (Kinchla and Wolfe, 1979; Eriksen & Schultz, 1979; Greaney & MacRae, 1992; Fink et al. 1996) found that varying stimulus size altered the order of processing. Kinchla and Wolfe (1979) presented subjects with stimuli that subtended progressively larger areas of the retina. They found that stimuli in excess of 6° of visual angle resulted in local dominance as indicated by faster responses to local than to global stimuli. Smaller hierarchical stimuli that subtended less than 6° elicited faster responses to the global level and so exhibited global dominance. This effect was likely due to the degree to which the stimuli fell on peripheral or foveal portions of the retina. In the case of the larger stimuli, the majority of the stimulus fell on the peripheral, low-resolution region of the retina thus degrading the perception of the global level and giving rise to faster response to local features. Conversely, small stimuli that fell entirely on foveal receptors resulted in shorter RTs to the global level. These results implied that the global level of an object was not necessarily processed first and that the order of processing was partly dependent on the size of the object.

Other groups found that the duration of exposure to hierarchical stimuli affected whether the global level was processed before the local level. At exposure durations of 10 msec, global interference on the local level (unidirectional interference) and shorter RTs to the global level were consistently found, implying global precedence. At durations of 100 msec and longer, however, bidirectional interference and equal RTs to the global and local levels were obtained (Paquet & Merikle, 1984; Martin, 1979; Hoffman, 1985). These authors proposed that, at longer exposure durations, local information could accumulate to the degree that it interfered with processing of the global level. This observation suggested that, at an early perceptual stage of processing, global precedence was observed because local information was not available. As exposure duration increased, local information was integrated sufficiently to compete with global information and global dominance was undermined.

In addition to manipulations of stimulus parameters, manipulating attentional influences can undermine the global precedence effect. If manipulating the level to which attention is directed results in local interference on the global level, this would undermine the notion that there is a mandatory processing priority in the perceptual analysis of global features. Moreover, when global precedence does occur, manipulating the direction of attention may provide some indication of the stage of processing that global dominance emerges. In a study that examined these issues, Paquet and Merikle (1988) presented subjects with two hierarchical objects in the left and right visual fields simultaneously. One of these objects was to be attended and the other ignored. They found that, for an attended object, the global aspect was identified more quickly and was more difficult to ignore than the local level. Although this result is congruent with a global precedence hypothesis, Paquet and Merikle also noted that when attention was directed to the local level of an attended object, it was more difficult to ignore the identity of the local than the global aspect of a non-attended object. That is, the direction of attention appeared to dictate which level of a non-attended object would impose the greater influence on processing. Despite the apparent dominance of global information, it is evident that information at the local level of a non-attended object can affect object processing, depending on the level of an attended object to which attention is directed.

Paquet and Merikle (1992) attempted to induce local processing dominance by engaging subjects in extensive practice with identifying targets at the local level in hierarchical displays. Subjects attended to a Navon stimulus in one visual field while a second, non-attended Navon stimulus was present in the other visual field. In the attended objects, extensive local practice eliminated global dominance. This result was evident in bidirectional interference and equal

RT to the global and local levels. In non-attended objects, extended local practice resulted in the automatic categorization of local features. However, this local practice effect only occurred when the experimental task was highly similar to the practice task. Although Paquet and Merikle eliminated global precedence, they were unable to induce local precedence despite practice with local-level target identification.

That global precedence prevails despite numerous efforts to undermine it is a testament to the robustness of this phenomenon. Unless perception of local features is facilitated by manipulations that enhance their perceptual discriminability relative to global features, global dominance persists. Evidence from behavioural experiments has accumulated to support the notion that processing of the global features of an object is obligatory and occurs earlier than processing of local features.

Cerebral Lateralization in the Processing of Hierarchical Objects

There are marked differences in the abilities of each of the cerebral hemispheres. In the majority of brains, the left hemisphere carries out speech, language and analytic functions while the right hemisphere is biased to perform visual-spatial tasks and more holistic functions (Lezak, 1993; Springer & Deutsch, 1993). In light of the proposed analytic/holistic organization of the brain, several investigations have been made into the lateralization of global (holistic) and local (analytic) processing mechanisms.

Studies in which a hierarchical object is projected to one hemisphere show that the two hemispheres have different biases in the processing of the global or local features of an object. When a stimulus is presented peripherally and for a brief duration (i.e. tachistoscopic presentation), it is received exclusively by the hemisphere contralateral to the visual filed in which the stimulus appeared (for a review, see Gazzaniga, 1998). Although visual information is transported to the ipsilateral occipital lobe via the splenium portion of the corpus callosum, it is initially received by only one hemisphere.

Several groups have found behavioural evidence in normal subjects for cerebral lateralization in the processing of global and local features (Blanca, Zalabardo, Garcia-Criado & Siles, 1994; Kimchi & Merhav, 1991). For example, in an investigation of exposure duration, Blanca et al. (1994) found different RT and accuracy advantages for global and local stimuli depending on the hemisphere to which the stimulus was presented. At 50 ms exposure, subjects were more accurate and responded faster to global targets when the stimulus was presented in the left visual field and received in the right hemisphere (LVF/RH). RT and accuracy were superior for local targets presented in the right visual field and received in the left hemisphere (RVF/LH). Blanca et al. (1994) and others concluded that the left hemisphere is biased for local level processing while the right hemisphere is biased for global level processing.

Spatial Frequency Hypotheses

Spatial frequency hypotheses centre on the notion that the global features of an object are composed of low spatial frequencies while the local elements are composed of high spatial frequency information (Sergent, 1982; Hughes, Nozawa & Kitterle, 1996). Sergent (1982) proposed a low-level, stimulus-bound hypothesis for lateralization of global and local processing. Based on her experiments with Navon-like stimuli, she proposed that each of the hemispheres is biased to process a different level of spatial frequency: the left hemisphere is sensitive to high spatial frequencies and the right hemisphere responds deferentially to low spatial frequencies. This difference results in an advantage for local stimuli in the left hemisphere and an advantage for the global aspect of a stimulus in the right.

At very early stages of processing, the global precedence effect may be dictated by the sensitivities of retinal and geniculate cells to low and high spatial frequencies. Based on this notion, Hughes, Nozawa and Kitterle (1996) proposed a physiological explanation for the spatial frequency hypothesis.

Visual information is carried from the retina to visual cortex via two parallel pathways. The magnocellular pathway conducts information from cells in the periphery of the retina that have large receptive fields and is concerned with gross features of objects. That is, the magnocellular pathway deals with low spatial frequency information. The parvocellular pathway receives input from retinal cells located in the fovea that have small receptive fields (Kandel, 1985). So, the parvocellular pathway is primarily involved in transmitting information about detail or high spatial frequency information.

Because magnocellular information is transmitted via large axons capable of fast conduction rates, the flow of information from retina to geniculate to cortex is more rapid in the in the magnocellular than in the parvocellular pathway (Kandel, 1985). As a result, the arrival in cortex of low spatial frequency information may precede the arrival of high spatial frequency information. Because the global aspect of an object is composed of low spatial frequencies, that level may arrive in cortex first and confer a temporal advantage to the global level very early in processing (Hughes et al., 1996).

The spatial frequency hypothesis deals with low-level, early stages of hierarchical object processing. However, several authors have proposed that at middle stages of processing, attentional factors, among others, may influence both the level that dominates and the lateralization of global/local processing mechanisms (Kinchla & Wolfe, 1979; Kitterle, Christman, & Hellige, 1990; Brown & Kosslyn, 1995; Greaney & MacRae, 1992). Kitterle et al. (1990) had subjects indicate as quickly as possible whether each of two sinusoidal gratings was composed of wide or narrow bars. One grating measured 1 cycle per degree (cpd) and constituted the wide bars or lower spatial frequency condition. Another grating measured 3 cpd and represented the narrow bar or higher spatial frequency condition. A single grating was presented in either the left visual field/right hemisphere (LVF/RH) or the right visual field/left hemisphere (RVF/LH).

Kitterle et al. found the typical pattern of RT advantage seen in processing of hierarchical objects. Subjects showed an RT advantage for 1-cpd gratings presented to the left visual field and an RT advantage for 3 cpd gratings presented to the RVF. Moreover, when Kitterle and his colleagues asked subjects to make similar judgements for 3 and 9 cpd gratings, the subjects then judged the 3-cpd gratings as having wide bars. That is, a stimulus that was initially judged as being composed of high spatial frequencies was later judged as having low spatial frequencies merely by virtue of the comparison required. Moreover, these subjects showed an LVF advantage for the 3 cpd grating. In light of the role of spatial frequency in global/local stimuli, this result strongly suggests that top-down factors contribute to the identification of global and local forms. Indeed, Brown and Kosslyn (1995) argue for a model of hierarchical processing in which the role of top-down allocation of resources is stressed rather than an account in which processing of hierarchical stimuli is bound to specific cortical structures.

Neuropsychological evidence for lateralization of hierarchical processing

Continued interest in the lateralization of hierarchical object processing has fuelled the search for cortical substrates of global/local processing. Using the Navon stimuli and methods described above, neuropsychological studies of brain-injured patients and brain imaging studies of normal subjects have provided evidence for putative locations of the mechanisms that participate in global/local processing. Although a significant portion of current knowledge of the function of particular brain areas has come from studies of brain injured individuals, accurate interpretation of the effects of lesions is difficult. Several factors must be kept in mind when drawing conclusions from the behaviour of patients with cortical lesions.

Acquired brain damage can result from traumatic head injury or internal events such as strokes, tumours or aneurysms. Widespread lesions frequently result from these events and often produce a constellation of deficits. Consequently, drawing inferences about the function of a cortical region from the location of damage and observed cognitive deficits can be somewhat tenuous (Reitan & Wolfson, 1993). In addition, one cannot be certain whether a lesion has damaged an area that generates a particular behaviour or whether a neural pathway linking critical areas has been compromised.

The brain compensates for damage, particularly in the acute stages

(Teuber, 1975). As a result, the behaviour observed is that which is present after compensatory mechanisms are in place. This recovery of function interferes with concluding that a site that has been damaged was responsible for producing a specific behaviour.

The authors of the following studies that draw on neuropsychological evidence stress that they include only those patients that are several years' post-injury and who are clinically stable. Although this condition is important, it fails to address concerns regarding compensatory mechanisms. Because of early recovery, the mechanisms underlying global/local processing in these patients may not accurately reflect the function of those mechanisms in intact individuals. The authors also note the complexity of interactions among brain areas and concede that caution is necessary in interpreting their findings (Lamb & Robertson, 1988).

Nevertheless, brain damaged patients produced consistent results in a number of neuropsychological studies of global/local processing. Responses from patients who sustained left hemisphere lesions differed from responses of patients with right hemisphere lesions. This result was evident in their respective abilities to reproduce from memory the Rey-Osterreith Figure. This figure, often used in the course of neuropsychological assessment, is a complex line drawing that contains both global and local aspects. Whereas patients with widespread left hemisphere lesions recalled the global aspect or outline of the original picture, patients with large right hemisphere lesions produced only the local details of the drawing (Robertson & Lamb, 1991). This dissociation suggested that the two hemispheres responded differently to global and local features. Left hemisphere patients were unable to recall the local aspect of the figure suggesting that the left hemisphere may be biased for processing local features. Similarly, because the right hemisphere patients failed to recall the global form, the right hemisphere may be biased for global processing.

In a similar study, left and right hemisphere patients drew hierarchical figures in which a global triangle was composed of local boxes (non-linguistic stimuli) and a global 'M' was formed from local 'z's (linguistic stimuli) (Delis, Robertson & Efron, 1986). Figure 2 illustrates responses from left and right hemisphere patients. Predictably, left hemisphere patients failed to recall local details and produced only the global forms while right hemisphere patients drew only local features. These effects occurred regardless of the category of stimuli. The left and right hemispheres, which are biased for linguistic and non-linguistic stimuli respectively, performed in the same way whether linguistic or non-linguistic stimuli were used. In other words, the global/local processing asymmetry was independent of the category of stimulus employed. Again, the left hemisphere and right hemisphere showed a bias for the local and global features respectively.

Robertson, Lamb and Knight (1988) examined global/local processing in patients with lesions that were confined to the posterior portion of one hemisphere. The temporal-parietal junction (TPJ) of either the left or the right hemisphere of each of the patients was compromised. Neurophysiological and anatomical evidence from animal studies showed that the TPJ has a role in visual perception and visual-spatial attention (Wurtz, Goldberg & Robinson 1985; Posner, 1984). The left TPJ patients were further subdivided into those having lesions centered in the left superior temporal gyrus (LSTG) and those with damage to the rostral inferior parietal lobule (LIPL). Previous neuropsychological studies had implicated these regions in visual discrimination (LSTG) and allocation of attention to locations in the visual field (LIPL). Robertson et al. (1988) found that the LSTG subjects showed an even greater advantage for the global level of a Navon stimulus and the RSTG patients displayed an advantage for the local aspects of the stimulus.

This evidence suggests that the left TPJ is involved in processing of local stimuli while the right TPJ deals with the global form of a stimulus. As well, because the LSTG subjects had the control over allocation of attention seen in normals but LIPL patients did not, Robertson et al. (1988) postulated that the LIPL region may control the allocation of attentional resources. These authors further proposed that each of the hemispheres is capable of processing both global and local information. However, the left hemisphere may be biased for processing the local level while the right hemisphere is biased for processing global information. Once processed for level, this information is then integrated by an interaction between the left and right STG. Such an interaction would be mediated via the corpus callosum (Robertson, Lamb & Zaidel, 1993). I will discuss results from my studies that support this hypothesis.

Based on their work with lesion patients, Polster and Rapcsak (1994) suggested that when one hemisphere responds to the appropriate level, it actively inhibits processing of the remaining level in the other hemisphere. This notion explains why an increased global advantage was observed by Robertson et al. (1988) in their LSTG group. The destruction of local level processors resulted not only in a decreased ability to process local information but also released the right hemisphere global processing mechanisms from inhibition by the left hemisphere.

In an extension of their previous work, Lamb and Robertson (1989) and Lamb, Robertson and Knight (1990) showed that interference between the two levels could be dissociated from speed of processing, that is global or local RT advantage. LSTG patients showed a global RT advantage while RSTG patients showed a local RT advantage. However, interference effects in which information at one level interferes with processing of the attended level were absent in both cases. That is, level advantage and interference varied independently. This effect is seen in normal subjects as well (Navon & Norman, 1983; Robertson et al., 1989). The absence of interference effects in STG patients led Lamb et al. (1989) to hypothesize that, in those patients, both the local and the global levels were processed but were not integrated. In conjunction with the notion that there are separate mechanisms for global and local processing, these results implied that separate mechanisms were responsible for level advantage and for interference. Furthermore, if interference and RT are independent then these effects cannot be taken together to infer global precedence nor serial processing of the levels.

Parallel Processing

Many investigators interpreted Navon's seminal work to mean that the global and local levels are processed serially: the global level receives priority in perception and processing begins before local information is available. However, evidence from some behavioural and neuropsychological studies of hierarchical processing has fostered the hypothesis that the mechanisms that subserve global/local processing operate in parallel. (Lamb & Robertson, 1989; Heinze & Munte, 1993; Shedden & Reid, submitted). One can discriminate between serial and parallel processing by examining electrophysiological responses of the brain as the cognitive task in question is performed. These measurements reveal the temporal nature of cortical processes and, to a degree, their spatial distributions.

The function of the cerebral cortex depends on the summed activity of many neurons within a neuron population. The electrical signals generated by these neurons can be measured non-invasively through the use of macroelectrodes applied to the scalp and recorded by an electroencephalograph (EEG). The aggregated voltage fluctuations that arise from the activity of a neuron population under the recording electrode result in upward or downward voltage deflections in the observed waveform (Martin, 1985).

When a continuous EEG is time-locked to a stimulus, a recording of event related potentials (ERPs) can be obtained. That is, by pairing the onset of a particular stimulus or cognitive task with a specific point in the EEG, one can observe the cortical activity associated with that task. Signal-averaging techniques are applied to the ERP so that the signal from brain activity associated with a task is differentiated from background activity unrelated to the task. This procedure produces an ERP waveform that describes only the cortical activity involved in the task. Thus, the human brain can be investigated as it is engaged in cognitive processes (Rugg, 1993).

ERPs provide precise information about the time course of neuroelectric events as they occur in cognitive tasks. In addition, although less exact, ERPs yield information about the spatial location of the neural generators involved in such processes. The primary advantage of using ERP to elucidate cognitive processes is that ERP is sensitive to the temporal range at which neurons operate. Thus, evaluation of the latencies, amplitudes and polarity of ERP components contributes to an understanding of the activity of the underlying generators and how this activity relates to cognitive processes (Gevins, 1996).

Although ERP affords superior temporal resolution, precisely determining the spatial location of the neural generators responsible for the activity is difficult. In ERP studies, electrical responses from a population of neurons are recorded at a site some distance away from the source of the electrical activity. In addition, these signals, which are minute to begin with, must traverse highly resistive barriers like the dura, skull, muscles, scalp, and hair. Both of these factors result in a distortion or blurring of the potential distribution at the scalp, which make it difficult to localize the sources of activity. Fortunately, spatial enhancement algorithms such as the Laplacian derivation and the Hjorth procedure, exist to minimize this distortion in the final analysis (Gevins, 1996).

Despite localization problems, ERP offers a direct measure of the way in which neural activity changes over the course of a cognitive task. By measuring changes in latencies and amplitudes of ERP components, inferences can be made concerning task-associated processes such as prestimulus preparation, target perception, attentional factors, response selection and response execution (Gevins, 1996).

Inferences about lateralization (i.e. gross spatial localization) and the order of processing are possible as well. By analyzing the latencies and amplitudes of ERP components associated with processing of global or local stimuli, deductions can be made concerning lateralization (i.e. gross spatial localization) of the processing mechanisms. Lateralization is evident when a component differs in morphology across the hemispheres depending on whether attention is directed globally or locally. For example, if in the case of processing of a global stimulus, the amplitude of a component is enhanced over one hemisphere but not over the other, then one could infer that the hemisphere in which enhancement occurred had a greater role in processing the stimulus. This interpretation is further supported if attention to the local level resulted in the opposite pattern of enhancement.

In addition, examination of the latencies at which components occur reveals whether processing takes place in parallel. Electrophysiological evidence for parallel processing is derived when activation arising from attention to the global level is concurrent with activation arising from attention to the local level. If components associated with processing of these conditions occur at the same latency, then evidence exists that the stimuli were processed in parallel. One would deduce serial processing if the latency of a globally activated component preceded the latency of a locally activated component. Thus, ERPs aid in discriminating serial from parallel processing.

Heinze and Münte (1993) undertook an electrophysiological analysis of global/local processing to determine whether it proceeds in parallel. They were motivated by the assertion of Lamb and Robertson (1989a, 1989b, 1990) that RT and interference effects were dissociable. Therefore, RT and interference effects could not be taken together as evidence for serial processing of the levels. This finding raised the possibility that processing of the levels occurs in parallel. Heinze and Münte (1993) conducted an ERP analysis of global/local processing to illuminate the temporal characteristics of global/local processing without having to rely on behavioural measures. These authors used a divided attention paradigm in which subjects identified a target at the global or local level in centrally presented small (2°) and large (7°) hierarchical stimuli. In these stimuli, global letters were formed from spatially arranged local letters.

Because Heinze and Münte employed a divided attention paradigm, the effect of interference of one level on the other was examined by varying the physical similarity relations between targets and distractors. The block letter H was deemed similar to the letter A but dissimilar to S and E. Likewise, the letter S was considered similar to E but different from H and A. However, similarity relations among the stimuli were not tested empirically.

All four letters served as targets. Although the response requirements are not clearly stated in the Heinze and Münte paper, the details of their method can be deduced from their discussion of their rationale for using similarity relations to elicit interference effects. It appears that, at the beginning of a trial, subjects were advised of the letter that would be the target for that trial. As the trial proceeded, subjects responded to the target letter as it appeared at either the global or the local level. Stimuli were composed of various combinations of the letters such that trials in which the target was presented along with similar distractors were interspersed with trials in which the target was presented with dissimilar distractors. Note that information presented at both the global and local levels changed from trial to trial. Interference was measured as the RT cost incurred to process a target when the letter at the unattended level was dissimilar versus when it was similar. ERPs were recorded as subjects performed the task.

Behaviourally, subjects responded to the global level faster than to the local level in the 2° condition, indicating a speed of processing advantage for the global level when stimuli were small. Conversely, RT to the local level was shorter than RT to the global level in the 7° condition, indicating an advantage for the local level when stimuli were large. However, targets were responded to faster when distractors were similar than when they were dissimilar regardless of stimulus size. Therefore, RT effects were dissociable from interference effects. These results were consistent with those in the Lamb and Robertson (1989) study.

However, a cautionary note regards the paradigm employed by these authors and the interpretation of the resulting ERP data. Subjects were advised of the target letter before a trial commenced but they were not advised of the level at which the target would appear. Thus, subjects would necessarily be engaged in some undetermined period of visual search before the target was located. During this search, one could not be certain of the level to which the subject is attending. The effect on the interpretation of ERP waveforms is that the early components would be more indicative of visual search processes than of global/local processing.

ERPs showed that the global and local levels first became differentiable at a negative component 250 ms (N250) after stimulus onset. This component, usually interpreted as an index of stimulus processing, was larger in the left hemisphere for local attention and larger in the right hemisphere for global attention. Recall that this pattern of similar time courses but different spatial distributions of activation for each of the levels is evidence for parallel processing by separate mechanisms. Moreover, lateralization of global processing to the right hemisphere and local processing to the left hemisphere is in the direction consistent with behavioural and neuropsychological literature.

Results from work in our laboratory suggest that the degree of variability at the unattended level influences global and local processing. In a directed attention task in which Navon-like hierarchical stimuli were composed of digits, Shedden and Reid (submitted) found equal RTs and errors for the levels when distractors at the unattended level were simple boxes. Moreover, interference effects were absent: information at either level did not interfere with processing of the attended level. That is, global precedence was eliminated. However, when distractors were of the same category as targets at the attended level (i.e. digits were presented at both levels), a global RT advantage and unidirectional interference were observed as global precedence emerged. As well, subjects responded to stimuli in the box distractor condition significantly faster than to stimuli in the digit distractor condition.

In the box distractor condition, information at the unattended level was invariant and, in that case, global dominance was not evident. However, in the digit distractor condition, information at the unattended level varied in that the digit distractor was different on every trial. Thus, distractor variability appears to influence allocation of spatial attention to object level: as variability increases, a processing priority for global features emerges. Moreover, because equal RTs were observed but interference effects were absent in the box distractor condition, these authors provided evidence that the local level is processed along with global information at least when distractor variability is absent (Shedden & Reid, submitted).

These findings invite investigation into attentional processes that may govern responses to hierarchical objects. Brown and Kosslyn, (1995) suggested that top-down allocation of attentional resources has a much greater role in hierarchical processing than reliance on lateralized, structurally fixed processing mechanisms. However, I propose that an attentional mechanism acts to influence the activity of fixed, lateralized neural populations that process global or local stimuli. I investigate this hypothesis in the experiments that follow.

Most global/local studies have employed a divided attention task in which responses are consistently mapped. Navon (1981) claimed that focused or directed attention tasks were limited in their usefulness because of their sensitivity to practice. Indeed, Paquet and Merikle (1988) found that global/local processing was susceptible to extensive practice. However, in ERP studies of hierarchical processing, it is imperative that the experimenter is certain that a subject is attending to a specified level for the duration of the ERP epoch that is assumed to be associated with processing of that level. A directed attention task is necessary to accomplish this. In the following experiments, the issue of practice effects is circumvented by the use of a varied mapping task. In such tasks, a particular target is associated with more than one response. In consistent mapping tasks, a particular target is always mapped to the same response. Evidence suggests that consistent mapping tasks foster automaticity or practice effects whereas varied mapping tasks do not (Schneider & Shiffrin, 1977). Thus, a varied-mapping, directed attention task facilitates analysis of

ERP data that is not confounded by practice effects.

In the following experiments, global and local processing mechanisms are engaged by using a number sequence task (NST). Here, hierarchical, Navon-like stimuli are built from digits rather than letters. This demanding task requires the subject to monitor an ascending sequence of digits at a specified level and respond to out-of-sequence digits. The continuous and unpredictable presentation of targets requires that the subject maintain attention at the specified stimulus position and level. In the detection tasks that are commonly used in global/local studies, a subject can release attention from the task momentarily and return to it in sufficient time to respond to the next target. In that case, one could not assume sustained attention to the designated level. With the NST, however, the subject must maintain vigilance on every frame or he will lose his position in the sequence and a marked reduction in accuracy will be apparent. If the subject is successfully detecting targets presented at a particular level, I can be sure that attention is fixed at that level. Therefore, I can be confident also that the ERPs collected during a particular trial are associated with the processing of the specified level.

In experiments 1a and 1b, I examine the effect on global/local processing of the presence or absence of variability at the unattended level. Shedden and Reid (submitted) noted striking changes in behavioural responses to hierarchical stimuli as variability at the unattended level was manipulated. Recall that global precedence disappeared when distractors were neutral boxes. However, when variability at the unattended level increased in the digit distractor condition, global precedence and unidirectional interference were observed. I examine the electrophysiological correlates of these changes and report very early, pre-response differences in brain activity that arise from manipulation of variability at the unattended level.

The goal of this experiment set is to examine very early processing of hierarchical stimuli and to produce evidence for lateralized processing of the levels. As others have reported, I report evidence that the levels are processed in parallel. However, I show that the earliest point of differentiation between the levels changes depending on the degree of variability at the unattended level. Indeed, in the box distractor condition, the levels can be distinguished electrophysiologically at an earlier processing stage than previously reported.

Experiments 2a and 2b include conditions in which subjects switch attention between levels and between horizontal visual fields while distractor variability is manipulated. Switching attention in an already difficult task should increase the demand on the system, particularly in the digit distractor condition. I examine how this manipulation will affect the global-right hemisphere/local-left hemisphere lateralization. When subjects switch among visual fields and levels, will the pattern of lateralization of global/local processing mechanisms persist? Or, to expedite processing under difficult conditions, will the system rely only on the hemisphere receiving the stimulus regardless of whether that hemisphere is biased for processing the attended level? Moreover, how will variability at the unattended level affect switching attention between the levels?

Experiment 1a: Box Distractors

Method

Subjects: Six subjects (four females and two males) participated in this experiment and received a small stipend for their efforts. All subjects were right-handed as assessed by a subset of the handedness questionnaire outlined in Steenhuis and Bryden (1989). Right-handedness was established if subjects indicated that they used their right hand exclusively or usually on eight of ten items in the questionnaire. Subjects ranged from 24 to 38 years of age: the mean age was 30.4. Finally, all subjects reported that they had normal or corrected to normal vision.

Procedure: Subjects sat in front of a computer screen. A chin rest was in place to ensure that the distance between the subject and the screen, and so the retinal size of the stimulus, remained constant. Subjects were given verbal instruction regarding the number sequence task as well as six practice trials prior to participating in the actual experiment.

In the Number Sequence Task, the subject views a computer screen which displays two hierarchical figures, one in each visual field. In the visual field to which the subject is instructed to attend, the figure is composed of digits and boxes while the figure in the nonattended visual field contains a box-shaped figure composed of smaller boxes. In the attended visual field, the subject is further instructed to monitor an ascending sequence of digits that occurs at the global or the local level of the figure. Occasionally, an out-of-sequence digit disrupts the sequence and necessitates a response from the subject. For example, in the sequence 1, 2, 3, 4, 8, 6, 7, 8, 9, 1, ..., the first 8 is a target. Upon detecting a target, subjects indicate their responses by pressing a specified key on the computer keyboard with the right hand. While the number sequence is presented at either the local or the global level of the hierarchical figure, the non-attended level and the figure in the non-attended visual field contain simple box distractors (Appendix A1). These distractors remained the same on every frame. At the beginning of each trial, the subject was presented with a cue display that indicated the spatial location of the stimulus and the level at which the sequence would appear. After the cue, the subject initiated a block of trials by pressing the spacebar and the number sequence was presented in consecutive trials until the end of the block. An example of this multiple frame procedure is given in Appendix A2.

Global digits were 5.2 cm high X 3.5 cm wide and subtended a visual angle of 5.94° X 4.00°. The local characters within the global stimulus were 0.5 cm X 0.3 cm and subtended 0.57 X 0.34 °. The stimulus appeared 2.29 degrees to the left or right of a fixation cross. In the non-attended visual field, a stimulus appeared that was composed of boxes at both the global and local levels (Appendix A1).

Subjects were instructed to remain fixated on the central cross at all times. They were also instructed to maintain their attention on the stimulus and not shift their gaze to look directly at it. Stimulus duration was 100 msec. Stimulus onset asynchrony was selected randomly from a rectangular distribution ranging from 850 to1050 ms with an average SOA of 900 ms. There were 72 real trials with each trial lasting 20 sec. The stimuli were presented by Micro Experimental Lab (MEL) software (Schneider, 1988).

Apparatus: Before sitting at the computer, subjects were fitted with an elasticized cap (ElectroCap International) mounted with 64 pure tin electrodes. Electrodes were distributed over the scalp as illustrated in Appendix A4. All electrodes were referenced to the right mastoid. Eye movements and blink activity were monitored by leads placed supraorbitally and at the external ocular canthi. Prior to recording, each electrode was adjusted to maintain impedance below 5 kilo-ohms (kΩ) at scalp sites and below 10 kΩ at orbital sites. A continuous EEG was recorded from the 64 channel montage and amplified by an SA Instrumentation Isolated EEG Bio-electric amplifier system. The recording bandwidth was .1-100 Hz and the signal was digitized at 400 Hz.

At the onset of a trial, a signal was sent from the MEL program to the computer that collected the EEG. Thus, the point in the continuous EEG at which a trial began was known and so facilitated division of the continuous EEG into segments containing activity associated with cortical processing of the trial.

The ERP was analyzed off-line. The data were digitally filtered using a low-pass 60 Hz filter. To remove the bias of the reference location, a Laplacian distance-weighted common average reference was applied using Hjorth's algorithm (Hjorth, 1980).

From the continuous EEG of each subject, segments corresponding to trials of the same type were averaged together. Segments of the EEG that contained eye blinks or other artefact were discarded. Peak amplitudes and latencies were determined for each subject by examining a subject's ERP waveform and manually selecting windows of time that encompassed the peak of each component. This step was necessary because there was a considerable degree of variability among subjects in the amplitudes and latencies of the ERP components. Individual peak amplitudes and latencies were averaged together to obtain a grand average of all subjects. Of the 64 electrodes, paired posterior electrodes were selected for analysis. These electrodes lay over the temporal-occipital-parietal cortex.

ERP data are presented in two ways. The waveform shown in Figure 3a represents ongoing processing at one critical site and so reveals the temporal nature of the processing involved in the task. Thus, waveforms provide temporal but not spatial information. Figure 3b illustrates a voltage map or topology. Here, the distribution of voltage changes over the entire scalp is represented. Topologies permit a view of processing at all sites but only at a single time point and so provide spatial but not temporal information.

Topologies were mapped by digitizing electrode locations and fitting these locations to a sphere. Although the head is obviously not spherical, such models facilitate the necessary mathematical computations. Finally, a spherical spline interpolation was implemented to produce the voltage maps (Perrin, Pernier, Bertrand & Echallier, 1989).

Results

Behavioural Analysis

The independent variables of interest behaviourally were Attended Level (global or local) and Attended Visual field (left or right). Recall that attention to a stimulus in the left or right visual field implies reception of the stimulus in the right or left hemisphere respectively.

Subjects were slower to respond to local targets presented to the LVF/RH and were less accurate with local targets in both visual fields. A two-way repeated measures ANOVA of Attended Level (global vs. local) by Visual field (LVF/RH or RVF/LH) was conducted on the mean response accuracy and on the mean response times. There was a significant main effect of Level ($F_{1,5} = 11.76$, $p<.05$) on accuracy indicating that subjects were more accurate in responding to targets at the global level (0.96) than the local level (0.92).

Although there were no significant main effects of Level or Visual field on RT, a significant interaction between Level and Visual field was obtained ($F_{1,5} = 7.74$, $p<0.05$). Newman-Keuls post-hoc comparisons indicated that subjects responded more slowly to local targets presented in the LVF (556 ms) than to any other level or location. RTs did not differ among the global level in either visual field (global/LVF = 537 ms; global/RVF = 539 ms) or the local level in the

RVF (544 ms). Analysis of response times for the box and digit distractor (Experiment 1b) conditions is presented graphically in Figure 4. A summary of means and standard deviations is presented in Table 1.

ERP analysis

ERP results are presented for each component in succession. Standard nomenclature requires that the first positive-going wave is named the P1 component, the first negative-going wave is the N1 component, the second positive wave is the P2 component and so on through N2 and P3 (Figure 5). Both the latency and peak amplitude of each of the components were analyzed.

Two sites, one over occipital-temporal-parietal cortex of each hemisphere, were the focus of this analysis (Appendix A4). They were selected because neuropsychological studies implicate the temporal-parietal junction in processing global/local stimuli (Robertson et al., 1988). Indeed, lateralized differences in global/local processing were most evident at these locations.

Experiments were designed for analysis of non-target trials to eliminate contamination of ERP data by motor responses. Because this was a directed attention task, it was not necessary to rely on target trials to obtain data regarding electrophysiological correlates of attention to one level or the other. Recall that this task necessitated that the subject maintained attention to the stipulated level for the duration of the trial.

Peak amplitudes and latencies of ERP components collected from non-target trials were subjected to three-way repeated-measures analyses of variance (ANOVA). The levels of interest were Channel (left hemisphere or right hemisphere) X Level (global or local) X Visual Field (left visual field or right visual field). Newman-Keuls Post Hoc comparisons were performed on significant main effects and interactions. This particular comparison was selected because of the low power encountered with the relatively few subjects involved in these experiments. However, I was able to maintain adequate conservatism as Newman-Keuls is neither the most nor the least conservative of the post hoc tests (Linton & Gallo, 1975).

Peak Latency

No significant differences were evident between components arising from global and local attention. For both Levels, the P1 component occurred at 85 ms, N1 at 145 ms, and N2 at 255 ms.

Peak Amplitude

P1 component: A significant Channel X Level interaction was noted at P1 and is illustrated in Figure 6a ($F_{1,5} = 11.98$, $p < .05$). Topographical representation is given in Figure 6b. Post Hoc comparisons of the two-way interaction showed that processing of a global stimulus in the right hemisphere elicited a larger P1 than processing of a local stimulus in the RH. In the figures, significant differences between pairs of means are indicated with an asterisk. The mean amplitudes were 5.78 μv versus 4.89 μv respectively, which yielded a difference of 0.89 μv ($p<.05$). The opposite effect occurred in the LH where local-level processing resulted in a larger P1 than global-level processing. Here, the amplitude difference of 0.34 μv was not statistically significant ($p=0.24$).

N1 Component: A main effect of Level ($F_{1,5} = 11.22$, $p<.05$) was seen at N1 and is shown in Figure 7a. Topologies of this effect are presented in Figure 7b. The N1 amplitude resulting from attention to the global level was 1.87μv greater than N1 for local attention. This occurred regardless of the visual field to which attention was directed.

N2-Component: The mean peak amplitudes at N2 are illustrated in Figure 8a; topologies are shown in Figure 8b. A significant Channel X Level interaction was evident ($F_{1,5} = 6.83$, $p<.05$). Newman-Keuls Post hoc comparisons revealed that for LVF attention, a global stimulus (-2.21 μv) elicited a significantly lower N2 amplitude than did a local stimulus (-2.95 μv). Similar N2 amplitudes were seen for global and local stimuli presented in the RVF.

As well, a significant three-way interaction was obtained from this analysis ($F_{1,5} = 8.09$, $p<.05$). Here, Newman-Keuls Post hoc comparisons indicated a significant difference between RH and LH activation at N2 arising from attention to global and local stimuli. A global stimulus presented in the LVF/RH produced a smaller N2 (-1.55 μv) than a global stimulus presented in the RVF/LH (-3.58 μv). Also, the global stimulus in the LVF/RH was significantly less negative than a local stimulus appearing in the RVF/LH (-3.87 μv). The three-way interaction is illustrated in Figure 8a.

Discussion

In Experiment 1a, the box distractors at the unattended level were constant from trial to trial within all blocks of trials. Thus, there was no variability at the unattended level in this experiment. As I will eventually discuss, the presence or absence of variability at the unattended level has a significant impact on global/local processing. This is evident both behaviourally and electrophysiologically.

Behaviourally, subjects in Experiment 1a were equally accurate when responding to either global or local features. As well, under most conditions, subjects responded to global and local stimuli with equal speed when information at the unattended level was held constant. Because RT was generally unaffected whether subjects were responding to global or local stimuli, this suggests that global and local information were available at the same time. Furthermore, it suggests that processing of the two levels proceeds in parallel.

However, when attention was directed to a local stimulus appearing in the left visual field (and so received in the right hemisphere), RT increased. This may have occurred because of the difficulty that this particular condition presents to the system. Consider that the local stimulus is presented to the hemisphere that is not biased for processing it. This circumstance leads to slower processing of local features in the LVF even when there is minimal distraction at the unattended level. This anomalous result does not detract from the parallel processing hypothesis discussed above: Although behavioural response was slower when a local stimulus was received in the RH, it does not necessarily follow that local information was not available to the system concurrently with global information. All that can be said logically is that the system was slower to process the stimulus. I will discuss ERP evidence that supports this latter explanation.

Because behavioural accuracy was sufficiently high, I was confident that ERPs obtained from a particular condition were indicative of cortical processing of that condition. ERP results from Experiment 1a further support the notion that processing of global and local features proceeds in parallel and, additionally, that it is lateralized. Moreover, I provide evidence that an electrophysiological distinction between the levels can be made much earlier in processing than previously reported.

Each of the components present in visual ERPs represents a particular stage in the processing of the stimulus. Some agreement has been reached regarding the interpretations of these voltage deflections as they relate to activity in the underlying neuron populations.

ERPs collected in Experiment 1a illuminate the influence of visual-spatial attention as it facilitates processing of global and local stimuli. To examine electrophysiological manifestations of global/local processing, I examine changes in the amplitudes and latencies of components that result from attention to each of the levels. An increase in the amplitude of a component, or enhancement, may result from increased activity or more synchronous firing within the neuron population located under the recording electrode. In later-appearing, endogenous components that are sensitive to higher cognitive processes (Coles & Rugg, 1995), I propose that more synchronous firing provides an index of cognitive effort expended during processing wherein increased amplitude indicates increased cognitive effort. In the early, exogenous components, however, attention may act to prime the neuron population that will receive the stimulus by inducing more synchronous firing within the neuron population (Mangun & Hillyard, 1990).

In this experiment, where variability at the unattended level is absent, attentional influences are evident as early as the P1 component. P1 is an exogenous, sensory component elicited by the appearance of an object in the visual field. However, P1 can be modulated by attention as it acts to facilitate early sensory processing for a location to which attention is already directed (Luck, Heinze, Mangun & Hillyard, 1990; Mangun & Hillyard, 1990; Rugg, 1991). Recall that a directed attention paradigm is used in these experiments.

Differences between global and local processing are evident at P1 in this experiment (Figures 6a and 6b). Not only was there enhancement in the receiving hemisphere because of attention to the contralateral visual field, but this enhancement varied depending on whether attention was directed to the global or local level. P1 resulting from attention to the global level (P1-global) was enhanced relative to P1-local when the attended hierarchical object was in the LVF and thus received in the RH. The reverse was seen for RVF/LH attention: P1-local was enhanced relative to P1-global. (This latter effect was not statistically significant but that is likely due to a lack of statistical power). Thus, when a global stimulus is expected to be delivered to the RH, spatial attention acts to enhance activity in the neuron population biased for processing global features. Conversely, the neuron population in the LH that is biased for processing local features is primed when local features are expected in the LH.

The role of spatial attention in priming the appropriate neuron population is further substantiated when P1-global and P1-local are examined over the hemisphere that receives the unattended figure. P1s elicited by the unattended stimulus are of equal amplitude because attentional factors are not differentiating between the global and local levels of this stimulus. Thus, evidence from P1-global and P1 local in both the attended and unattended figures is congruent with the hypothesis that global processing is lateralized to the RH and local processing is lateralized to the LH.

Although striking differences were evident in the P1 amplitudes elicited by attention to one level or the other, P1 latencies were equal. That is, global information is available to the system at the same latency that local information is available. This implies that processing begins in parallel. These findings undermine the hypothesis that global information is perceptually available earlier than local information. Thus, the presence of lateralized amplitude differences for global and local attention, along with equal latencies for P1-global and P1-

local, combine to support the notion that global and local information are processed in parallel by separate, lateralized mechanisms. ERP data from Experiment 1a clearly indicate that, under some conditions, a distinction between processing of the levels can be made at 85 ms after stimulus onset rather than the 250 ms previously reported (Heinze and Münte, 1993).

The influence of spatial attention on the processing of global and local features continues to be evident at subsequent ERP components. Frequently, the N1 component is interpreted as an index of the orientation of spatial attention to a relevant object (Mangun & Hillyard, 1987). In the context of this experiment, N1 illustrates a further refinement of orientation of attention such that orientation to the global level is distinguishable from orientation to the local level (Figures 7a and 7b). Regardless of the visual field to which attention was directed, global attention always elicited an N1of greater amplitude than did local attention. However, N1-global was significantly greater than N1-local only over the hemisphere receiving the attended stimulus. Although lateralization of global/local processing is not apparent at N1, the peak amplitude occurred at the same latency for global and local attention. Thus, parallel processing of the two levels is evident at N1 also.

Several analogies have been made to describe how attention acts to select for further processing a portion of the visual field that contains relevant information. These metaphors include a ‘spotlight’ of attention in which a facilitation of processing is extended to stimuli falling within the boundaries of the spotlight (Posner, Snyder & Davidson, 1985). Others proposed a similar spotlight description but, rather than having discrete all-or-none boundaries, the size of the spotlight could be made to vary as required by task demands and stimulus characteristics (LaBerge, 1983). In an examination of ERP correlates of spatial attention, Mangun and Hillyard (1987) found that N1 amplitude varied depending on the distance to which attention was extended into the periphery. Thus, evidence suggests that N1 gauges orientation of attention to a relevant stimulus.

In terms of global and local processing, I interpret the difference in N1 amplitude brought about by attention to global or local features as resulting from sizing of an attentional window to accommodate the relative sizes of the global or local forms. When subjects attended to the global level, a hypothetical attentional window was sized to accommodate the larger global form where relevant information was located. When subjects attended to relevant information at the local level, spatial attention acted to reduce the size of the window because local elements occupy a smaller portion of the visual field.

The N2 component is an endogenous component and is thought to be a function of stimulus evaluation and classification processes (Mangun & Hillyard, 1995; Coles & Rugg, 1995). In this experiment, N2-global was consistently less negative than N2 local (Figures 8a and 8b). Moreover, when information at the unattended level was held constant, N2s elicited by global attention were quite flattened relative to N2s resulting from local attention; N2-local exhibited a marked peak. Under the assumption that increased amplitude reflects greater cognitive effort, it appears that global features required little processing effort compared with the greater effort required to process the local features.

The amplitude difference between N2-global and N2-local was greatest in the hemisphere contralateral to the attended visual field. A large difference between global and local N2 occurred when a global stimulus was attended in the LVF in which N2-global was much less negative than N2-local. Current views of lateralization of global and local processors dictate that a global stimulus appearing in the LVF/RH should be the easiest condition for the system to process because the global stimulus enters the preferred hemisphere. The amplitude of the N2 resulting from global attention in the LVF was the least negative, and thus stands as electrophysiological evidence that global processing is lateralized to the RH.

Lateralization of local processing mechanisms to the LH was also evident at N2. When attention was directed to the RVF, N2-local was more negative over the LH than the RH. This result illustrates the effort expended by the LH but not the RH in the processing of a local stimulus.

In summary, Experiment 1a examined global and local processing when variability at the unattended level was absent. This was achieved by engaging subjects in a demanding task that occurred at the attended level of a Navon-like stimulus. At the unattended level, box distractors were presented and were invariant from frame to frame. Evidence was gathered for lateralization of global information processing to the RH and local information processing to the LH. Moreover, global and local processing proceeded in parallel. Finally, global and local processing were distinguishable electrophysiologically 85 ms after stimulus onset. In the next experiment, I examine the effect on global/local processing of the presence of variability at the unattended level.

Experiment 1b: Digit Distractors

Method

Subjects: Six subjects (five females and one male) participated in Experiment 1b. and received payment for their participation. Each of these subjects was right-handed and reported normal or corrected to normal vision. Subjects ranged from 23 to 28 years of age and the mean age was 26.7 years.

Procedure: The procedure in this experiment was similar to that used in Experiment 1a. In Experiment 1b, however, subjects received digit distractors at the unattended level of the attended hierarchical figure instead of the box distractors presented in Experiment 1a. These digit distractors changed on every frame presented (Appendix A3). These distractors were generated in random order with the following restrictions. In frames containing a target at the attended level, the digit at the non-attended level was never the same as the in-sequence digit nor was it ever the same as the target digit. Also, the same digit distractor did not appear in two consecutive trials. As well, the figure in the non-attended visual field was composed of local level digits that formed a global digit. The digit components of the figure in the non-attended visual field also changed on every frame. The two experiments were identical in all other respects. Please refer to the methods section in Experiment 1a for general details.

Apparatus: Behavioural and ERP data were collected from subjects as they completed the task. The apparatus and method of obtaining these data are described in the appropriate sections of Experiment 1a.

Results

Behavioural analysis

Subjects in this experiment were somewhat less accurate than in Experiment 1a, but not significantly so. Two-way repeated measures ANOVAs of Attended Level (global vs. local) by Visual field (LVF/RH or RVF/LH) were conducted on the mean response accuracy and mean RT. There was a significant main effect of Level ($F_{1,5} = 10.32$, $p < .05$) indicating that subjects were more accurate in responding to targets at the global level (0.91) than at the local level (0.86).

A main effect of Level on RT was almost achieved ($F_{1,5} = 5.88$, $p = .059$) in which subjects responded to the global level (569 ms) faster than to the local level (591 ms). Although this effect falls short of statistical significance, that is probably due to a lack of power and is considered to be a real effect. Analysis of response times for box and digit distractors is presented in Figure 4. A summary of means and standard deviations is given in Table 1.

ERP analysis

Peak amplitudes and latencies of ERP components collected from non-target trials were subjected to three-way repeated measures ANOVA. The levels of interest were Channel X Level X Visual Field. Newman-Keuls Post Hoc comparisons were performed on significant main effects and interactions.

Peak Latency

No significant differences were evident between components arising from global and local attention. For both levels, P1 occurred at 85 ms, N1 at 145 ms and N2 at 245 ms.

Peak Amplitude

P1 Component: At P1, there were no differences among left or right hemisphere, global or local levels and left or right visual field. That is, in the digit condition, P1 amplitudes were equal for both levels in both hemispheres. P1 waveforms and topologies are presented in Figures 9a and 9b.

N1 Component: There were no effects of Level, indicating that similar N1 amplitudes were elicited by global and by local attention. However, a significant Level X Visual Field interaction occurred ($F_{1,5} = 10.67$, $p<.05$) and is shown in Figure 10a. Newman-Keuls Post hoc analysis revealed that LVF attention resulted in peaks of nearly equal amplitude in the left (-9.75 μv) and right (-9.70 μv) hemispheres. However, when attention was directed to the RVF, N2 peaks were 2.23 μv greater in the right hemisphere than the left hemisphere ($p<.05$). Topologies of N1 amplitudes are given in Figure 10b.

N2 Component: Figure 11a illustrates the analysis that was performed on the mean peak amplitudes at N2. A significant Level X Visual Field interaction occurred ($F_{1,5} = 8.89$, $p<.05$). Newman-Keuls Post hoc comparisons indicated that a local stimulus in the LVF elicited the largest N2 (-3.89 μv). It was significantly different ($p<.05$) from the N2 arising from a global stimulus in the LVF (-2.63 μv)) or RVF (-3.06 μv). A global stimulus in the LVF/RH resulted in the smallest N2 peak (-2.63 μv). Figure 11b illustrates the topologies for N2.

Discussion

Digit distractors at the unattended level in Experiment 1b constitute the condition in which variability is present at the unattended level. As a result of this variability, the information at the unattended level becomes potentially relevant and, as I will discuss, has a striking impact on the behavioural and electrophysiological responses to hierarchical stimuli.

In contrast to behavioural performance in the box distractor experiment, subjects in Experiment 1b were more accurate when responding to out-of-sequence digits at the global level than when performing the task at the local level. As well, the pattern of response times was different between these experiments wherein subjects consistently responded faster at the global level than at the local level. Moreover, subjects responded approximately 40 ms faster regardless of level when distractors were simple boxes than when distractors were digits. Thus, when variable information was presented at the unattended level, the global precedence effect emerged: RT to global information was shorter than for local information and unidirectional interference was observed.

The effect of variability at the unattended level was dramatically demonstrated in the ERPs collected from these subjects. As in Experiment 1a, subjects in this experiment were accurate enough that ERP data was considered a true reflection of cortical processing of the specified level.

The impact of mutable stimuli at the unattended level was apparent in all ERP components. Inspection of Figures 9a and 9b reveals that the P1s elicited by global and local attention overlapped completely. As was seen in the box distractor condition, latencies of the P1 components in this experiment were equal and indicate that local information was available along with global information whether variability at the unattended level was present or absent. Thus, ERPs at the P1component further support the parallel processing hypothesis.

In contrast to Experiment 1a, global and local attention elicited P1s of equal amplitude in both hemispheres. That is, evidence for lateralization of global and local processing mechanisms was apparently lost. Paradoxically, however, this occurrence can be explained by lateralization of global and local mechanisms. When the stimulus was received in the hemisphere biased for processing the attended level of the stimulus (e.g. a global stimulus in the LVF), enhancement of P1 similar to that seen in Experiment 1a was observed. At the same time however, the potentially relevant information at the unattended level demanded attention and the mechanism in the other hemisphere biased to process that information was initiated. Thus, variability at the unattended level produced an enhanced P1 component similar to that which resulted from processing of the attended level.

Because subjects were exposed to the digit distractors from the outset, potentially relevant information at the unattended level was expected. The system responded to this expectation by maintaining global and local processing mechanisms in an active state. This explains why the impact of variability on global/local processing is evident as early as P1. A test of this hypothesis would entail presenting subjects randomly interspersed box distractor and digit distractor trials. Based on the present discussion, equally enhanced P1s for both global and local attention should persist for all trials, not only trials containing digit distractors. This would occur because potentially relevant information may or may not be present and the system would prepare itself for the possibility that variability might occur.

This pattern of equal enhancement for each of the levels persisted at the N1 component. Considering that N1 gauges the orientation of attention to relevant (and potentially relevant) stimuli, one would anticipate that variability at the unattended level would influence the N1 component. Indeed, N1s for global and local attention were completely overlapping (Figures 10a and 10b).

In terms of the spotlight metaphor of attention, the pattern of N1 enhancement observed in this experiment may have resulted because the attentional spotlight was kept sufficiently large to accommodate both the global and local levels. Recall from Experiment 1a that N1 was enhanced for global attention but was relatively less negative for local attention. This was interpreted as an effect of the size of the attentional spotlight. In the present experiment, the spotlight of attention was sized to be sufficiently large so as to accommodate the global form. Even when subjects attended to the local level, variability occurring at the global level necessitated maintaining an attentional spotlight large enough to include potentially relevant global information.

In contrast to the very early distinction observed between global and local processing in Experiment 1a, global and local processing do not become differentiable until N2 (245 ms) under the conditions of this experiment. Although N2s resulting from global attention were morphologically different from N2-local, the peak amplitudes occurred at the same latency. This observation provides continuing support for the parallel processing hypothesis.

As observed in the box-distractor experiment, N2s resulting from processing of a global stimulus were less negative than N2-local. However, whereas N2-global was flattened when distractors were boxes, N2-global was comparatively enhanced in the digit distractor condition (Figures 11a and 11b). On the supposition that enhancement of an endogenous component signifies increased cognitive effort, it appears that the system devotes more effort to processing the global level when there is variability at the unattended local level. This view is contrary to behavioural evidence that suggests that local distracting information has no impact on global-level processing. These ERP data show that, although the time course of global processing is not altered, processing global information requires more effort.

Lateralization of global and local processing mechanisms is evident in ERP data at N2 in the digit distractor condition. When variability was present at the unattended level, the electrophysiological indicator of local processing was absent over the RH whether attention was directed to the RVF or the LVF. Moreover, when attention was directed locally in the LVF, N2-local was significantly greater over the LH than for local attention in the RVF/LH. This observation suggests that evaluation of a local stimulus presented in the LVF, indexed by N2, appeared not to be conducted in the RH where it was initially received. Because the RH is not biased for processing the local level, processing appeared to be transferred to the LH where it could proceed with greater efficiency.

The notion that information is transferred to the neuron population best suited for processing it is congruent with the hypothesis of Robertson. Lamb and Zaidel (1993) in which they discuss lateralization of global/local processing. They proposed that once a hierarchical stimulus has been processed for level by the appropriate hemisphere, the information is integrated by an interaction, mediated by the corpus callosum, between the left and right superior temporal gyri. A pathway designated for integrating global with local information could also serve as a route through which level information could be transferred to the hemisphere biased for processing it.

Thus, when variability was present at the unattended level and a stimulus was received by the hemisphere less efficient at dealing with it, the hemisphere biased for processing the attended level was engaged. This observation supports the hypothesis that global and local processing mechanisms are structurally fixed: processing of a level is carried out in the hemisphere that is biased for processing that level whether or not the stimulus was initially received in that hemisphere.

Heinze and Munte (1993) and Heinze, Hinrichs, Scholz, Burchert and Mangun (1998) reported that global and local processing were separable first at the N2 component (250 ms) even in a directed attention version of their task. However, they, and in the majority of studies to date, employed stimuli in which variability at the unattended level was always present. This is comparable to the digit distractor experiment in the present work in which global and local processing is not distinguishable until 245 ms.

In summary, the presence of variability at the unattended level has a significant impact on behavioural and electrophysiological markers of global/local processing. When stimuli at the unattended level are not constant, the system treats those stimuli as having potentially relevant information and allocates attentional resources to them. I propose that variability at the unattended level results in contributions from both hemispheres very early in processing and the hemisphere biased to process information at the unattended level is engaged.

The next experiments examine the behavioural and electrophysiological impact of switching attention among levels and visual fields. In addition to providing a replication of Experiments 1a and 1b, these experiments corroborate findings regarding lateralization and parallel processing even when task difficulty increases. Indeed, subjects reported that the task they were required to perform in Experiment 2 was particularly difficult. Data from several subjects who participated in the digit distractor condition in Experiment 2b were discarded because they performed at little better than chance levels.

Experiment 2a: Box Distractors

Method

Subjects: Ten right-handed, paid subjects, six of whom were female, participated in Experiment 2a. Subjects ranged from 23 to 38 years of age. The mean age was 29.7 years. Finally, all subjects reported that they had normal or corrected to normal vision.

Procedure: The procedure in this experiment was similar to that used in Experiment 1a. As in that experiment, subjects monitored the NST at the position(s) and level(s) specified in the cue frame while box distractors were presented at all unattended locations.

In this attention switching experiment, trials were added in which subjects were required to switch attention between levels, visual fields or levels and visual fields. Specifically, subjects were instructed at the cue frame regarding the level and visual field to which attention should be directed. The conditions were as follows: fixed in the right or left visual field, fixed on the global or local level (Experiment 1a, 1b replication); fixed in the left or right visual field, switching from global to local; fixed in the left or right visual field, switching from local to global; switching from the right to the left visual field, fixed on global; switching from the left to the right visual field, fixed on local; switching from the right to the left visual field, switching from global to local; switching from the right to the left visual field, switching from local to global; switching from the left to the right visual field;

switching from global to local and, finally, switching from the left to the right visual field; switching from local to global.

Experiment instructions and stimulus parameters were the same as those applied in Experiment 1a. However, in this experiment, subjects received 16 practice trials and 96 real trials.

Apparatus: The description of the apparatus used in Experiment 1a is directly applicable to this experiment.

Results

Behavioural Analysis

Four-way repeated-measures ANOVAs of Attention Type: VF (Fixed in or Switching across visual fields) X Visual Field (LVF or RVF) X Attention Type: Level (Fixed on one level or Switching between levels) X Attended Level (Global or Local) were performed on subjects' response times and accuracy.

There was a main effect of Attention Type: Level ($F_{1,9} = 13.24$, $p < .01$) in which subjects responded 14 ms faster when attention switched between levels than when attention was fixed on one level. As well, an interaction among Attention Type: VF X Visual Field X Attended Level was present in mean RT data ($F_{1,9} = 5.47$, $p < .05$). Examination of Figure 12a reveals that subjects were faster at switching in the RVF than in the LVF, regardless of the attended level. Moreover, the pattern reversal was observed between the Fixed and Switching VF conditions: Subjects were equally fast in both VFs for local attention when they were fixed on VF but were equally fast in both VFs for global attention when they switched between VFs. Additionally, when attention was fixed on VF subjects responded to a global stimulus in the RVF faster (522 ms) than to a global stimulus in the LVF (538 ms). When attention switched between VFs, subjects responded fastest to a local stimulus in the RVF (526 ms) and slowest to a local stimulus in the LVF (537 ms). Although global and local RTs interacted significantly whether attention was fixed on or switching VF, Newman-Keuls Post Hoc comparisons indicated that these differences among global and local mean RT were not significant. Means and standard deviations for RT are presented in Table 2.

With respect to subjects' accuracy, main effects of Attention Type: VF and Visual Field were observed. The main effect of Attention Type: VF ($F_{1,9} = 8.30$, $p < .05$) revealed that subjects were more accurate when attention was fixed on a visual field (0.92) than when attention switched between visual fields (0.90). Also, the main effect of Visual Field ($F_{1,9} = 8.30$, $p < .05$) showed that subjects were more accurate when they responded to targets in the LVF (0.91) than to targets in the RVF (0.92) regardless of the attended level.

ERP Analysis

Peak Latencies

Channel (LH or RH) X Visual Field (LVF or RVF) X Level (Global or Local) repeated-measures ANOVAs were performed on the peak latencies of waveforms collected from bilateral occipital-temporal-parietal sites. For both global and local processing when attention was fixed on a visual field and level, the P1 component occurred at 89 ms, N1 at 155 ms and N2 at 255 ms. When attention was switching between visual fields and between levels, global and local processing resulted in P1 at 88 ms, N1 at 155 ms and N2 at 245 ms.

Peak Amplitudes

Peak amplitudes of all components of interest were subjected to three-way repeated-measures ANOVAs of Channel X Visual Field X Level. Results of the analysis of each component are presented for the condition in which attention was fixed on visual field and level and for the condition in which attention switched among visual fields and levels.

P1-Fixed: No main effects of Channel, Visual Field or Level were observed. However, a significant interaction occurred in which RVF attention resulted in a P1 amplitude over the RH that was 1.1μv less positive than over the LH. P1 over the RH was also less positive than P1s over both hemispheres that resulted from LVF attention ($F_{1,9} = 14.86$, $p < .01$). This interaction is illustrated in Figure 13c.

P1-Switching: There were no differences in P1 amplitudes when subjects switched attention among visual fields and levels. Waveforms and topologies representing P1 amplitudes for the Fixed and Switching conditions are given in Figures 13a and 13b.

N1-Fixed: A main effect of Visual Field showed that N1 arising from LVF attention was 1.16 μv less negative than RVF attention ($F_{1,9} = 12.71$, $p < .01$).

Also, there was a main effect of Level in which N1-global was 1.46 μv larger than N1-local ($F_{1,9} = 16.40$, $p < .01$). A significant Channel X Level interaction ($F_{1,9} = 6.03$, $p < .05$) was seen in which N1-global was more negative over the RH than over the LH ($p < .01$). N1-local followed the same pattern ($p < .01$). Finally, a significant Channel X Visual Field X Level interaction ($F_{1,9} = 5.95$, $p < .05$) indicated that while N1-global was larger than N1-local in the LH, N1-local became as large as N1-global over the RH when a local stimulus appeared in the RVF. However, for LVF presentation, N1-local was 3.73 μv less negative than N1-global that arose from LVF presentation ($p < .01$). The three-way interaction is presented in Figure 14c.

N1-Switching: A main effect of Level was evident in this condition. As illustrated in Figure 14c, N1-global was 2.13 μv more negative than N1-local regardless of the attended visual field or the hemisphere in which the stimulus was received ($F_{1,9} = 7.79$, $p < .05$). Waveforms and topologies for the N1 component are shown in Figures 14a and 14b.

N2-Fixed: A main effect of Level is shown in Figure 15c. Attention to a local stimulus resulted in an N2 that was 0.52 μv more negative than N2-global ($F_{1,9} = 9.43$, $p < .05$). This result occurred regardless of the attended visual field or the hemisphere in which the stimulus was received.

N2-Switching: A main effect of level occurred in which N2-local was 1.30 μv more negative than N2-global ($F_{1,9} = 9.43$, $p < .05$). An interaction between Channel and Visual Field was found also ($F_{1,9} = 9.43$, $p < .05$) and is illustrated in

Figure 15c. Here, N1 was largest in the hemisphere that received the stimulus regardless of the attended level. Specifically, N1-LVF was more negative than N1-RVF over the RH and N1-RVF was more negative than N1-LVF over the LH ($p< .01$ in both cases). Figures 15a and 15b contain waveforms and topologies for N1.

Discussion

In this analysis, data was presented from conditions in which subjects performed the Number Sequence Task when their attention was fixed in one visual field and fixed on one level. These conditions are comparable to those presented in Experiment 1a and serve as a replication of that experiment. Replication is important because it suggests that the cortical processes that were engaged in Experiments 1a and 1b are the same those being tapped in Experiments 2a and 2b. Once it has been established that both experiments tap the same mechanisms, assertions can be made regarding additional manipulations such as those encountered in the switching conditions in Experiment 2. In the Switching conditions that I will discuss, subjects were required to switch their attention between visual fields and between levels. All conditions were performed while variability at the unattended level was absent.

Behaviourally, subjects showed no significant effects of Level indicating that subjects' RTs for global attention were not different from RTs for local attention. This pattern is the same as that observed in Experiment 1a. However, subjects did show that they were significantly faster in responding to a level when they were required to switch attention than when attention was fixed (Figure 12a). Moreover, an interesting reversal of global and local RT occurred in the interaction among Attention Type: VF, Visual Field and Attended Level. With respect to RTs in the Fixed on VF conditions, subjects responded to a global stimulus in the LVF/RH *slower* than any other condition. This result is not consistent with results from Experiment 1a nor with the behavioural and neuropsychological literature in which global processing is lateralized to and most efficiently processed in the RH. Although, differences between pairs of means were not significant the interaction is interesting from a theoretical standpoint and I present what I believe is a viable explanation.

Current hypotheses about the locus of spatial attention switching mechanisms posit that the right posterior parietal lobe is involved in the engagement and disengagement of spatial attention (Mesulam, 1981; Rafal & Robertson, 1995). Because the Switching trials in this experiment require that attention be repeatedly disengaged from one spatial location and engaged at another, the right posterior hemisphere would be active in the Switching conditions. However, the RH control of attention switching may also be active during Fixed trials: Considering that blocks of switching trials are interspersed with blocks of fixed trials, the system may maintain itself in a state in which it is prepared to switch because Switching trials appear at random. Because the system is at the ready for switching trials, this would necessitate inhibiting the tendency to switch VFs when a block of fixed trials is presented.

However, processing of the global level of a stimulus is also under the control of the right posterior hemisphere. Thus, during Fixed trials in which attention is directed to the LVF, not only does the RH process the global level, but it must also inhibit the disengage mechanism. This double-duty may tax attentional resources in the posterior RH and result in increased RT to a global stimulus presented in the LVF. The apparently anomalous finding that RT is longer for a global stimulus in the LVF in Fixed trails actually supports the lateralization of level processing mechanisms. Moreover, the hypothesis that RH inhibition occurs in Fixed trials also explains why RT in Switching trials is faster overall than RT in Fixed trials.

Electrophysiological data in this experiment provide additional support for the ERP related hypotheses presented in Experiment 1a. Recall in that experiment, where variability at the unattended level was absent also, the effect of selective attention on global/local processing was such that a distinction between processing of the levels was apparent at the P1 component (85 ms). Processing of the two levels continued to be differentiable for the duration of the ERP epoch. Moreover, evidence was presented to support lateralized, parallel operation of global and local processing mechanisms.

ERPs recorded in the fixed conditions of Experiment 2a revealed highly similar effects to those seen in Experiment 1a except at the P1 component.

Rather than being clearly separable as was observed in Experiment 1a, P1s resulting from global and local attention in this experiment were not statistically different. This finding may be due to the inclusion of conditions in which subjects switched attention between levels and visual fields. Because P1 denotes facilitation of the neuron populations in the hemisphere that will receive the stimulus, spatial attention may have acted to maintain neuron populations in a state of preparedness in all trials. That is, because blocks of trials that necessitated switching visual fields were interspersed with blocks of trials in which attention was fixed, neuron populations in both hemispheres remained activated throughout. Indeed, P1s recorded during the switching VF/switching level conditions were very similar in morphology to the P1s from the fixed VF/fixed level conditions: both hemispheres were in an activated state continually whether attention was fixed or switching (Figure 13a). Thus, lateralization of global and local processing mechanisms is not immediately evident at P1 in this experiment. However, parallel processing of the levels is supported because P1 amplitudes for global and local attention occurred at the same latency.

The N1 component indexes the orientation of spatial attention to a relevant location in the visual field. Results at N1 in this experiment replicate those of Experiment 1a, in which the amplitude of N1-global was greater than the amplitude of N1-local. Also, in Experiment 1a, N1-global was significantly more negative than N1-local over the LH for RVF attention and over the RH for LVF attention. N1-local and N1-global were of equal amplitude over the hemisphere receiving the non-attended stimulus (Figure 7a and 7b). In terms of the attentional spotlight analogy, when variability was absent at the unattended level, spatial attention acted to define the region of space in which relevant information was contained.

Although N1-global was more negative generally than N1-local in this experiment, the significant difference between N1-global and N1-local was observed only over the RH (LVF attention) for both the Fixed and Switching conditions (Figures 14a and 14b). That is, the specificity-to-level of spatial attention seemed to disappear over the LH (RVF attention). This effect may be a result of the additional load placed on the system by the requirement to Switch location and level. If the system maintains itself in a state in which it is always prepared to switch locations, it must inhibit the tendency to switch during Fixed trials. Because attention switching mechanisms are thought to reside in the RH, this additional load may render the system less efficient at orienting specifically to local features when they are presented to the LH/RVF. In Switching trials, however, a pattern more similar to that observed in Experiment 1a is present; N1-global is more negative that N1 local. Because the system is prepared to switch and the additional load of inhibiting switching is not a factor, orienting attention to local features in the RVF appears to be more efficient in the Switching conditions.

The N2 component reveals differences in the processing of global and local stimuli in the Fixed and Switching conditions. Recall that N2 is thought to result from evaluation of the stimulus. Moreover, I proposed earlier that enhancement of N2 indicated more effortful evaluation of the stimulus when task demands increased. This proposal stemmed from the observation that N2 arising from evaluation of a global stimulus was relatively flat when distractor variability was absent and indicated minimal cognitive effort. When variability was present in the more demanding digit distractor condition, however, N2 exhibited an obvious peak, indication greater expenditure of processing effort.

In the Fixed conditions of this experiment, the amplitude of N2-local was more negative than N2-global overall. In addition, the effects observed at N2 in this experiment replicated those of Experiment 1a: Evaluation of information at the global level apparently required less processing effort than evaluation of information at the local level. This effect is illustrated in the flattened N2-global and the relatively peaked N2-local seen in Figures 15a and 15b. Additionally, the more challenging task presented in the switching conditions results in a more peaked N2-global. Thus, the patterns observed at N2 in this experiment provide additional support for the hypothesis that more effortful processing results in enhancement of N2.

Indirect evidence for lateralization of global/local processing exists at N2 in both the fixed and switching conditions. Although the appearance of N2-global changes little regardless of the visual field to which attention is directed, N2-local shows some sensitivity to visual field. When attention is directed to the RVF and therefore received in the LH, N2-local shows a prominent peak, suggesting that a degree of effort is expended on evaluating the stimulus. However, when a local stimulus is attended in the LVF and received in the hemisphere that is not biased for dealing with the stimulus, processing in the RH seems to drop out. The presence of a pronounced N2-local over the LH for LVF attention suggests that processing of the stimulus is referred to the left hemisphere where it can be treated efficiently. This effect is also evident in the switching conditions and was observed in Experiments 1a and 1b.

Lateralization and parallel processing of global and local stimuli continued to be evident even when attention switched among visual fields and levels. That lateralization persists under these conditions suggests that global and local processing mechanisms are fixed in place. That is, global processing is referred ultimately to the RH and local processing is referred to the LH regardless of the hemisphere in which the stimulus is received initially. Mechanisms that direct spatial attention act to allocate processing of the levels to the appropriate hemisphere. The next experiment affords the opportunity to determine whether the effect of spatial attention persists when the additional load of variability is added.

Experiment 2b: Digit Distractors

Method

Subjects: Ten right-handed, paid subjects, seven of whom were female, participated in Experiment 2a. Subjects ranged from 24 to 27 years of age: the mean age was 26.3 years. Finally, all subjects reported that they had normal or corrected to normal vision.

Procedure: The procedure in this experiment was similar to that used in Experiment 2a. In Experiment 2b, however, subjects received digit distractors at the unattended level of the attended hierarchical figure instead of the box distractors presented in Experiment 2a. These digit distractors changed on every frame presented (Appendix A3). Digit distractors were generated in random order with the following restrictions. In frames containing a target at the attended level, the digit at the non-attended level was never the same as the in-sequence digit nor was it ever the same as the target digit. Also, the same digit distractor did not appear in two consecutive trials. As well, the figure in the non-attended visual field was composed of local level digits that formed a global digit. The digit components of the figure in the non-attended visual field also changed on every frame. The two experiments were identical in all other respects. Please refer to the methods section in Experiment 2a for general details.

Apparatus: Behavioural and ERP data were collected from subjects as they completed the task. The apparatus and method of obtaining these data are described in the appropriate sections of Experiment 2a.

Results

Behavioural Analysis

Mean RT and mean accuracy data from the distractor conditions were subjected to four-way repeated-measures ANOVAs of Attention Type: VF (Fixed in or Switching across visual fields) X Visual Field (LVF or RVF) X Attention Type: Level (Fixed on one level or Switching between levels) X Attended Level (Global or Local). Effects in this condition are illustrated in Figure 12 and in Table 2.

Overall, subjects responded to the global level 13 ms faster than to the local level ($F_{1,9} = 15.56$, $p< .01$). A main effect of Attention Type: Level indicated that subjects responded 15 ms faster to stimuli at either level when they were fixed on a level compared with when they were switching between levels ($F_{1,9} = 11.58$, $p< .01$). An Attention Type: VF X Visual Field interaction occurred ($F_{1,9} = 9.37$, $p< .05$). This interaction indicated that mean RTs for LVF attention where the same in both the fixed on VF and switching VF conditions. Although mean RTs for RVF attention were similar to those of LVF attention when attention was fixed on a visual field, subjects were faster than any other condition when they were switching attention in the RVF ($p< .01$).

With respect to accuracy, a main effect of Attention Type: Level ($F_{1,9} = 13.93$, $p< .01$) indicated that subjects were less accurate when switching between levels whether they were fixed on or switching visual fields (0.92 versus 0.86 respectively). Also, a three-way interaction among Attention Type: VF, Visual Field and Attention Type: Level was observed ($F_{1,9} = 6.34$, $p < .05$). This interaction revealed that subjects tended to be more accurate when attention was fixed on a level than when attention switched between levels. Subjects were least accurate when switching levels while fixed on the RVF ($p < .01$).

A four-way repeated-measures mixed ANOVA was performed on mean RTs in which the between-subject factor was Distractor Type (Box vs Digit distractors). Within-subject factors were Attention Type: VF (Fixed in or Switching across visual fields) X Visual Field (LVF or RVF) X Attention Type: Level (Fixed on one level or Switching between levels) X Attended Level (Global or Local). A main effect of Attended Level indicated that subjects responded to the global level 6 ms faster than to the local level ($F_{1,18} = 8.64$, $p < .01$).

Several significant interactions occurred in the comparison between box distractor and digit distractor conditions. These are illustrated in Figure 12b. There was an interaction between Distractor Type and Level ($F_{1,18} = 10.36$, $p < .01$) wherein subjects responded to both the global and local levels equally fast when distractors were boxes Figure 12b-1. However, when distractors were digits, subjects were 13 ms slower in responding to targets at the local level ($p < .01$). A Distractor Type X Attention Type: Level revealed that although mean RTs to boxes and digits were unaffected when attention was fixed on a level ($p = .74$), they were 20 ms faster at switching between levels when distractors were boxes

(529 ms) than when distractors were digits (549 ms) ($p < .01$) (Figure 12b-2). Finally, an Attention Type: Visual Field X Attention Type: Level interaction ($F_{1, 18} = 4.47$, $p < .05$) indicated that subjects were relatively fast when attention was fixed on level and fixed on visual field and when attention was switching between levels and switching visual fields (533 ms and 534 ms, respectively). The most problematic condition was that in which subjects switched attention between levels while fixed in one visual field (540 ms) (Figure 12b-3). However, Newman-Keuls Post Hoc comparisons revealed that these mean RTs were not significantly different from each other.

ERP Analysis

Peak Latencies

Channel (LH or RH) X Visual Field (LVF or RVF) X Level (Global or Local) repeated-measures ANOVAs were performed on the mean peak latencies of waveforms collected from bilateral occipital-temporal-parietal sites. For both global and local processing when attention was fixed on a visual field and level, the P1 component occurred at 85 ms, N1 at 150 ms and N2 at 260 ms. When attention was switching between visual fields and between levels, global and local processing resulted in P1 at 88 ms, N1 at 150 ms and N2 at 265 ms.

Peak Amplitudes

Peak amplitudes of all components of interest were subjected to three-way repeated-measures ANOVAs of Channel X Visual Field X Level. Results of the analysis of each component are presented for the condition in which attention was fixed on visual field and level and for the condition in which attention switched among visual fields and levels.

P1-Fixed: No significant differences were found at the P1 component. This result indicates that the amplitudes of P1s elicited by attention to either level were similar.

P1-Switching: A Channel X Visual Field interaction occurred in this condition and is illustrated in Figure 16c. P1 arising from LVF attention was greater over the LH than the RH. The opposite pattern was observed for RVF attention in which P1 resulting from RVF attention was greater over the RH than the LH ($F_{1,9} = 6.18$, $p < .05$). Waveforms and topologies that illustrate P1 amplitudes are shown in Figures 16a and 16b.

N1-Fixed: There were no significant differences for N1-Fixed. N1 amplitudes were equal among all conditions.

N1-Switching: There were no significant differences for N1-Switching. N1 amplitudes were equal among all conditions. Waveforms and topologies at N1 for both the Fixed and Switching conditions are presented in Figures 17a and 17b. However significant effects occurred between the Fixed and Switching conditions at N1. A Channel X Attention Type X Level ANOVA was done on the peak amplitudes at N1. A main effect of Attention Type was observed in which N1-Fixed was 1.8 μv less negative that N1-Switching ($F_{1,9} = 7.33$, $p < .05$). A Channel X Attention Type interaction ($F_{1,9} = 7.33$, $p < .05$) revealed that not only did Switching attention result in more negative N1s in general, but that N1 was most negative over the RH (Figure 17c).

N2-Fixed: A main effect of Channel approached significance ($F_{1,9} = 4.76$, $p = .0569$) but is considered a real effect because of the lack of power inherent in these experiments: N2 was 0.69 μv greater over the LH than the RH. A Visual Field X Level interaction revealed that while amplitudes of N2-global were similar regardless of the visual field in which the stimulus was presented, N2-local was significantly more negative for LVF attention than for RVF attention ($F_{1,9} = 6.88$, $p < .05$). This interaction is represented in Figure 18c.

N2-Switching: Main Effects of Channel and of Level were found. Also, a Channel X Visual Field interaction was observed and is illustrated in Figure 18c. In the Channel main effect, the N2 component was 2.12 μv more negative over the LH than over the RH ($F_{1,9} = 5.33$, $p < .05$). A main effect of Level approached significance ($F_{1,9} = 4.83$, $p = .0554$) and revealed that N2-local was .97 μv more negative than N2-global. The Channel X Visual Field interaction ($F_{1,9} = 13.97$, $p < .01$) showed that while N2s resulting from LVF attention were similar over both hemispheres, N2 for RVF attention was 4.45 μv more negative over the LH than the RH 9 (p< .01). Refer to Figures 18a and 18b for waveforms and topologies of N2 peak amplitudes.

Discussion

The conditions in Experiment 2b presented a considerable challenge to the system. In this experiment, subjects performed the NST while either fixed on or switching level and visual field. In addition, digit distractors that changed on every trial meant that potentially relevant information was present continually. Despite this degree of difficulty, subjects' RT and accuracy in performing the task were not notably different in the direction that one would anticipate, given the perceived degree of difficulty, from their performance in Experiment 1b. That is, one would expect that subjects would respond slower when task difficulty increased with the addition of switching conditions. However, in Experiment 1b, in which variability at the unattended level was present but subjects were not required to switch locations, global and local RTs were 569 and 591 ms respectively. In the present experiment (2b), which entailed attention switching, RTs to the global and local levels were 534 and 553 ms respectively. Thus, in both experiments the global precedence effect is apparent. Moreover, the pattern of accuracy was similar in Experiments 1b and 2b; subjects were more accurate for global attention than for local attention. Thus, a replication of Experiment 1b was obtained.

Subjects' response patterns to Fixed versus Switching conditions were different here from the pattern observed when variability at the unattended level was absent (Experiment 2a). In Experiment 2a, subjects were faster when attention switched between levels but subjects in the present experiment responded faster when attention was fixed on a level. The contributing factor in these conflicting results must be the presence of potentially relevant information at the unattended level as that is the only difference between the two experiments.

Subjects performed slowest when they were switching levels while fixed on visual field. This effect probably arose because, as the task was performed at the attended level on one frame, processing the information at the unattended level would have to be inhibited. However, on the very next frame, the previously ignored unattended level became the attended level because a level switch was required. In other words, the subject must immediately switch attention to and process information at the level that was just ignored. Moreover, because the unattended level contained potentially relevant information, inhibiting that level would likely require more effort than when invariant boxes appeared at the unattended level. This task is complicated further in that on half the level switches within a visual field, attention must be directed to a level that is received in a hemisphere not biased for processing that level.

Thus, the reasons that subjects were considerably slower when switching between levels within a VF were twofold: The variability at the unattended level was difficult to inhibit and resulted in an RT cost when information at that level had to be disinhibited in order to continue the task. As well, a transfer of information to the opposite hemisphere would be necessary when the attended level was directed to hemisphere less efficient at processing it. Thus, variability at the unattended level had a significant impact on global/local processing and contributes to behavioural evidence for simultaneous processing of information at both levels.

ERP data continue to support the parallel processing hypothesis that has been evident in all of these experiments: components arising from global or local attention occur at the same latencies. In addition, examination of the topographical distribution of the components lends further support to claims about the lateralization of processing. Finally, a comparison between ERPs recorded in the box versus digit distractor conditions speaks to the effect of the presence of potentially relevant information at the unattended level.

When subjects were fixed on level and visual field, P1 amplitudes were similar whether attention was directed globally or locally. This effect was observed also in experiment 1b and, rather than refuting the lateralization of processing hypothesis, actually served as evidence in favour of lateralization. As discussed in Experiment 1b, equal enhancement of P1s arising from global and local attention occurred because variability at the unattended level caused facilitation in the hemisphere that would be responsible for processing the potentially relevant information.

Similar P1 amplitudes were observed also in the Switching conditions. This result probably arises from the notion that the system appears to maintain itself in a state of preparedness: Because subjects were switching between visual fields, facilitation was maintained in the neuron populations responding to information in each of the visual fields. This effect was observed in Experiment 2a also.

Amplitudes at the N1 component were similar for both levels in the Fixed and in the Switching conditions. Variability was present at the unattended level whether attention was Fixed or Switching and, as proposed previously, the presence of this variability influenced the orientation of spatial attention. In the box distractor experiments (1a and 2a), N1 showed an effect of attention in which N1-local was less negative than N1-global. This effect was interpreted as the specific sizing of an attentional window to accommodate the relatively large area of visual space occupied by the global form and the smaller portion of the visual field occupied by the local form. In Experiment 1b and in the present experiment, however, potentially relevant information was present at the unattended level as well as at the attended level. In addition to orienting attention to the attended level, attentional resources were directed to the unattended level also and resulted in N1s of equal amplitude even when attention was directed locally. Thus, ERPs at N1 illustrate the manner in which attention is allocated to areas of the visual field that contain relevant or potentially relevant information.

An interesting effect between the Fixed and Switching conditions occurred at N1 and only in the digit distractor conditions: the following effects were not evident in the box distractor condition. As discussed above, N1s resulting from global or local attention were not different. However, when attention switched between levels and between VFs, N1 was significantly more negative than when attention was fixed (Figures 17a and 17b). Additionally, in the Switching conditions, N1 was significantly more negative over the RH than the LH. This enhancement of N1 over the RH may be related to the notion that spatial attention switching mechanisms reside in the right parietal lobe. Indeed, Hillyard et al. observed that N1 occurs 20-30 ms earlier over parietal cortex than N1 over occipital cortex (Hillyard, Munte & Neville, 1985). The parietal N1 in these data warrants further investigation.

Although N1 was more negative in the Switching condition, the orienting process gauged by N1 appears to proceed more quickly than in the Fixed condition. This assertion stems from the observation that the P2 component, which follows N1, peaks at the same latency for both the Fixed and the Switching conditions. Thus, despite having to rapidly re-orient spatial attention to the opposite level and VF, the system is not held back in subsequent stages of processing. This raises the notion that perhaps the various stages of processing (e.g. orientation, stimulus evaluation, response selection) occur within fixed periods of time: if circumstances prevail that impede optimum processing time, then the system “speeds up” some aspect(s) of processing to maintain the processing schedule.

Waveforms observed at N2 in the Fixed conditions of this experiment exhibit a somewhat different pattern of enhancement from those observed in Experiment 1b. Recall that in Experiment 1b, a noticeable peak was evident compared with the relatively flattened N2 in the box distractor condition of Experiments 1a and 2a. The enhancement of N2 for global attention in the presence of variability at the unattended level was interpreted to mean that processing of the global level required more effort than the case in which variability was absent. In this experiment, N2-global was flattened in appearance relative to N2-local. This finding is more similar to the patterns observed in the box distractor experiments than the previous digit distractor experiment.

This discrepancy at N2 may stem the degree of perceived task difficulty. Experiment 2b requires subjects to fix and/or switch attention between visual field and/or level while variability is present at unattended locations. Thus, the conditions in which attention is fixed on level and visual field may be perceived to be the least taxing of all the conditions. It is reasonable to think that the system can deal with this condition relatively effortlessly compared with the cognitive effort it must invest in the most difficult trials. A reduction in effort would be reflected in the N2 component. Indeed, in the Switching trials, the observed N2 pattern is consistent with the pattern observed in Experiment 1b wherein N2-global shows a marked peak. The enhancement of N2 is indicative of the increased effort required to process global information when the task is more demanding. This hypothesis does not undermine the assertion that the system seems to maintain itself in a state in which it is prepared to process the most difficult condition. That assertion concerned the early components (P1, N1) which serve to facilitate activity in both hemispheres so that all relevant information is available for further processing. As proposed earlier, N2 indexes the degree of cognitive effort expended on stimulus evaluation and stimulus processing. Thus, N2 would not necessarily be maintained in a state of readiness throughout al trials. N2 enhancement appears to indicate task specific effort rather than indicating on-going effort.

Finally, lateralization of processing was not immediately apparent at N2. However, in switching trials, N2-local was more negative over the LH for LVF attention. This effect may have occurred as processing of the local level was transferred from the RH to the LH for greater efficiency.

In summary, Experiment 2b provides further evidence that processing mechanisms in both hemispheres are engaged and maintained in a state of preparedness as task demands increase. However, processes related to the N2 component appear to be selective in that evidence for greater expenditure of cognitive effort only appears in the most difficult conditions. Moreover, even when task demands increase, evidence for lateralized parallel processing persists. Thus, evidence has accumulated to support the notion that global/local processing is relegated to structurally fixed mechanisms and it is the role of spatial attention mechanisms to direct information to the appropriate hemisphere for processing. In addition, observations made of the N1 component in the Fixed and Switching conditions support the notion that attention switching mechanisms are located in the right hemisphere.

Conclusions

Although the initial proposals from behavioural studies of hierarchical processing posited that global information was available earlier in perception than local information (Navon, 1977, 1981), the ERP data from my work provides clear evidence that global and local information are available concurrently. Moreover, processing of the levels is conducted in parallel throughout all the stages of processing regardless of task difficulty or the presence of potentially relevant information at unattended locations.

In addition, my data support the lateralization of global and local processing mechanisms: Although each hemisphere is capable of processing both global and local information, the RH is biased to process global information and the LH is biased to process local information. This evidence is congruent with findings from both brain-damaged and normal populations (Blanca et al.,1994; Delis et al., 1986; Robertson et al.; 1988; Lamb & Robertson, 1989, Lamb, et al., 1990). Even when task demands increase with the inclusion of variability at the unattended level and the requirement that attention switch among locations, lateralization of processing persists. Findings from my work permit the assertion that global and local processing is conducted in separate, lateralized neural mechanisms. Moreover, these mechanisms are fixed in place and activity within them is governed by attentional mechanisms.

The presence or absence of variability at the unattended level has a significant effect on behavioural and electrophysiological correlates of global/local processing and underscores the role of visual selective attention in the processing of these stimuli. When variability is absent, the influence of visual selective attention is apparent very early in the processing of the levels and serves to prime the receiving hemisphere for efficient processing of the global or local levels of stimulus. However, when potentially relevant information is present at the unattended level, attention is allocated to that level as well and processing of that level occurs. Evidence for this assertion was obtained when attention was directed to one level of a figure in one visual field but similar enhancement was observed over both hemispheres. This result indicated that hierarchical object processing mechanisms in both hemispheres were engaged when task demands increased, at least in the early stages of processing. In later stages, information processing is referred to the hemisphere that is biased for processing the level at which relevant information appears.

The apparent inability of the system to ignore variability at an unattended location has been referred to in the literature as a failure of selective attention (see Melara & Mounts, 1993). However, rather than permit the negative connotation implied by this term, I view the system's response to potentially relevant information in a positive light; attentional mechanisms act to include unattended information that may be significant. That selective attention "fails" when potentially relevant information is present at a location other than the attended location is biologically adaptive. Evidently, the system has built-in safeguards that permit a degree of distractibility so as to alert the organism to potentially hazardous stimuli that occur at a location other than the attended location. In other words, the system is susceptible to a degree of distractibility.

When distracting information is absent, an electrophysiological distinction between global and local processing can be made at a very early stage. This finding occurs because the system relies only on the hemisphere biased for processing the attended level when conditions permit. Indeed, I report that this distinction occurs at about 85 ms and to my knowledge, this is the earliest point at which processing of the levels has been discriminated and reported in the literature. Thus contrary to the views expressed by Heinze et al. (1993, 1998), global and local processing occurs in distinct and separate mechanisms from the beginning of processing.

However, when potentially relevant information is present at an unattended location, the levels are not separable electrophysiologically until about 250 ms. The early distinction between the levels is no longer evident because the hemisphere biased to process the information at the unattended level is engaged. Moreover, information at both levels is processed concurrently.

Future Direction

In addition to providing further evidence in support of lateralization and parallel processing of global and local stimuli, the experiments requiring switching of attention among visual fields and levels also point to the locus of attention switching mechanisms. Observation of patterns of enhancement at the N1 component implicated the RH as the locus of these mechanisms, an observation that is consistent with findings reported in the literature (Hillyard et al., 1985; Mangun & Hillyard, 1987). In the data obtained from my experiments, the location of switching mechanisms could be further refined by a comparison of parietal ERPs collected in the Fixed and Switching conditions; recall that other investigators have implicated parietal lobe as the locus of switching mechanisms (Mesulam, 1981; Rafal & Robertson, 1995).

Although outside the focus of this work, the wealth of ERP data collected in these experiments provides fertile ground for examining attentional systems in greater detail. Because the switching conditions in these experiments require switching between the levels of an object as well as between visual fields, the task may actually be tapping into two separate attentional systems. In a study of cortical activation in brain-damaged patients, Buck et al. (1997) proposed that while right superior parietal mechanisms allocate attention spatially, there may exist a left hemisphere mechanism that allocates attention within objects. This notion is of particular importance in delineating the manner in which attention is allocated to the levels of hierarchical objects.

References

Blanca, M. J., Zalabardo, C., Garcia-Criado, F. & Siles, R. (1994). Hemispheric differences in global and local processing dependent on exposure duration. *Neuropsychologia, 32 (11),* 1343-1351.

Buck, B. H., Black, S. E., Behrmann, M, Caldwell, C. & Bronskill, M. (1997). Spatial- and object-based attentional deficits in Alzheimer's disease: Relationship to HMPAO-SPECT measures of parietal perfusion. *Brain, 120,* 1299-1244.

Brown, H. D. & Kosslyn, S. M. (1996). Hemispheric differences in visual object processing: Structure vs. allocation. *In*. R. J. Davidson & K. Hugdahl (eds.). Brain Asymmetry. Cambridge: MIT Press.

Coles, M. G. & Rugg, M. D. (1995). Event-Related Potentials: An Introduction *In*. M. D. Rugg & M. G. Coles (eds.). Electrophysiology of Mind: Event Related Potentials and Cognition. Oxford: Oxford University Press.

Delis, D. C., Robertson, L. C. & Efron, R. (1986). Hemispheric specialization of memory for visual hierarchical stimuli. *Neuropsychologia, 24,* 205-214.

Eriksen, C. W. & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics, 25,* 249-263.

Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S. & Dolan, R. J. (1996). Where in the brain does attention select the forest and the trees?. *Nature, 382,* 626-628.

Gazzaniga, M. S. (1998). Cerebral Lateralization and Specialization. *In*. M. S. Gazzaniga, R. Ivry & G. R. Mangun (eds.). Cognitive Neuroscience: The Biology of the Mind. New York: W.W. Norton & Co.

Gevins, A. (1996). Electrophysiological Imaging of Brain Function. *In*. A. W. Toga & J. C. Mazziotta (eds.). Brain Mapping: The Methods. San Diego: Academic Press. 259-276.

Greaney, J. & MacRae, A.W. (1992). The order of visual processing: Top-down, bottom-up, middle out or none of these? *Bulletin of the Psychonomic Society, 30 (3),*255-257.

Grice, G. R., Canham, L. & Borroughs, J. M. (1983). Forest before trees? It depends on where you look. *Perception & Psychophysics, 33 (2),* 121-128.

Heinze, H. & Munte, T. F. (1993). Electrophysiological correlates of hierarchical stimulus processing: Dissociation between onset and later stages of global and local target processing. *Neuropsychologia, 31 (8),* 841-852.

Heinze, H. J., Hinrichs, H., Scholz, M., Burchert, W. & Mangun, G. R. (1998). Neural Mechanisms of Global and Local Processing: A Combined PET and ERP Study. *Journal of Cognitive NeurOscience 10(4)*, 485-498.

Hillyard, S. A., Munte, T. F. & Neville, H. J. (1985). Visual-Spatial Attention, Orienting and Brain Physiology. *in.* M. I. Posner & O. S. Marin (eds.).Hillsdale, NJ: Erlbaum

Hjorth, B. (1980). Source derivation simplifies topographical EEG interpretation. *American Journal of EEG Technology, 20,* 121-132.

Hoffman, J. E. (1980). Interaction between global and local levels of a form. *Journal of Experimental Psychology: Human Perception and Performance, 6*, 222-234.

Hughes, H .C., Layton, W. M., Baird, J. C. & Lester, L. S. (1984). Global precedence in visual pattern recognition. *Perception & Psychophysics, 35*, 361-371.

Hughes, H. C., Nozawa, G. & Kitterle, F. (1996). Global Precedence, Spatial Frequency, and the Statistics of Natural Images. *Journal of Cognitive Neuroscience, 8(3),* 197-230.

Kandel E. (1985). Processing Form and Movement in the Visual System. *In.* E. R. Kandel & J. H. Schwartz (eds.). Principles of Neural Science. New York: Elsevier.

Kimchi, R & Merhav, I. (1991). Hemispheric processing of global form, local form and texture. *Acta Psychologia, 76,* 133-147.

Kinchla, R. A. & Wolfe, J. M. (1979). The Order of Visual Processing: “Top-down,” “bottom-up” or “middle-out.” *Perception & Psychophysics. 25,* 225-231.

Kitterle, F. L., Christman, S. & Hellige, J. B. (1990). Hemispheric differences are found in the identification, but not the detection, of low vs. high spatial frequencies. *Perception & Psychophysics. 48,* 225-231.

Koffka, K. A. (1935). Principles of Gestalt Psychology. New York: Harcourt, Brace & World.

LaBerge, D. (1995). Attentional Processing: The Brain's Art of Mindfulness. Cambridge, Ms: Harvard University Press

Lamb, M. R., Robertson, L. C. & Knight, R. T. (1989). Attention and Interference in the Processing of global and local information: Effects of unilateral temporal-parietal lesions. *Neuropsychologia, 27(4),* 471-483.

Lamb, M. R. & Robertson, L. C. (1989). Do response time and interference reflect the order of processing of global- and local-level information? *Perception & Psychophysics, 46(3),* 254-258.

Lamb, M. R., Robertson, L. C. & Knight, R. T. (1990). Component Mechanisms Underlying the Processing of Hierarchically Organized Patterns: Inferences from Patients with Unilateral Cortical Lesions. *Journal of Experimental Psychology: Learning, Memory and Cognition. 16(3),* 471-483.

Lezak, M. (1993). Neuropsychological Assessment. New York: Oxford University Press.

Linton, M. & Gallo, P. (1975). The Practical Statistician. Monterey: Brooks/Cole Publishing Company.

Luck, S. J., Heinze, H. J., Mangun, G. R. & Hillyard, S. A. (1990). Visual event-related potentials index focussed attention within bilateral stimulus arrays: II. Functional dissociation of P1 and N1 components. *Electroencephalography and Clinical Neurophysiology. 75,* 528-542.

Mangun, G. R. & Hillyard, S. A. (1987). The Spatial Allocation of Visual Attention as Indexed by Event-Related Brain Potentials. *Human Factors. 29(2).* 195-211.

Mangun, G. R. & Hillyard, S. A. (1990). Electrophysiological Studies of Visual Selective Attention in Humans. *In.* A. F. Scheibel & A. B. Wechsler (eds.). The Neurobiology of Higher Cognitive Function. New York: Guilford Press.

Mangun, G. R. & Hillyard, S. A. (1995). Mechanisms and Models of selective Attention. *In.* M. D. Rugg & M. G. Coles (eds.). Electrophysiology of Mind: Event-Related Potentials and Cognition. Oxford: Oxford University Press.

Martin, J. H. (1985). Cortical Neurons, the EEG, and the Mechanisms of Epilepsy. *In.* E. R. Kandel & J. H. Schwartz (eds.). Principles of Neural Science. New York: Elsevier. 636-647.

Martin, M. (1979). Local and global processing: The role of sparsity. *Memory and Cognition, 7,* 476-484.

Melara, R D. & Mounts, J. R. (1993). Selective attention to Stroop dimensions: Effects of baseline discriminability, response mode and practice. *Memory and Cognition, 21(5).* 627-645.

Mesulam, M. (1981). A cortical network for directed attention and unilateral neglect. *Annals of Neurology, 10,* 309-325.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9,* 353-383.

Navon, D. (1981). The Forest Revisited: More on Global Precedence. *Psychological Research, 43,* 1-32.

Navon, D. & Norman, J. (1983). Does global precedence really depend on visual angle? *Journal of Experimental Psychology: Human Perception and Performance, 9,* 955-965..

Paquet, L., & Merikle, P. M. (1984). Global precedence: The effect of exposure duration. *Canadian Journal of Psychology, 38 (1),* 45-53.

Paquet, L., & Merikle, P. M. (1988). Global precedence in attended and non-attended objects. *Journal of Experimental Psychology: Human Perception and Performance, 14 (1),* 89-100.

Paquet, L., & Merikle, P. M. (1992). Global and Local Processing in Non-Attended Objects: A Failure to Induce Local Processing Dominance. *Journal of Experimental Psychology: Human Perception and Performance, 18(2),* 512-529.

Perrin, F., Pernier, J., Bertrand, O., & Echallier, J. F. (1989). *Electroencephalography and Clinical Neurophysiology, 72,* 184-187.

Polster, M. R. & Rapcsak, S. Z. (1994). Hierarchical stimuli and hemispheric specialization: two case studies. *Cortex, 30,* 487-497.

Posner, M. I., Snyder, C. R. & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General. 109,* 160-174.

Posner, M. I., Walker, J. A., Friedrich, F. J. & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience, 4,* 1863-1874.

Rafal, R. & Robertson, L. (1995). Neurology of Visual Attention. *In.* M. Gazzaniga (ed.). The Cognitive Neurosciences. Cambridge: MIT Press.

Regan, D. (1989). Human Brain Electrophysiology. New York: Elsevier

Reitan, R. M. & Wolfson, D. W. (1993). The Halstead-Reitan Neuropsychological Test Battery: Theory and Clinical Interpretation. Tucson, Arizona: Neuropsychology Press.

Robertson, L. C., Lamb, M. R. & Knight, R. T. (1988). Effects of Lesions of Temporal-Parietal Junction on Perceptual and Attentional Processing in Humans. *Journal of Neuroscience, 8(10),* 3757-3769.

Robertson, L. C., Lamb, M. R. & Knight, R. T. (1990). Component Mechanisms Underlying the Processing of Hierarchically Organized Patterns: Inferences from Patients with Unilateral Cortical Lesions. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16(3),* 471-483.

Robertson, L. C. & Lamb, M. R. (1991). Neuropsychological Contributions to Theories of Part/Whole Organization. *Cognitive Psychology, 23,* 299-330.

Robertson, L. C., Lamb, M. R. & Zaidel, E. (1993). Interhemispheric relations in processing hierarchical patterns: Evidence from normal and commissurotomized patients. *Neuropsychology, 7,* 325-342.

Rugg, M. D. (1991). ERPs and selective attention: commentary. *In.* C. H. Brunia, G. Mulder & M. N. Verbaten (eds.). Event-Related Brain Research. Elsevier Science Publishers.

Rugg, M. D. & Coles, M. G. (1995). The ERP in cognitive psychology: conceptual issues. *In*. M. D. Rugg & M. G. Coles (eds.). Electrophysiology of Mind: Event Related Potentials and Cognition. Oxford: Oxford University Press.

Schneider, W. (1988). Micro experimental laboratory: An integrated system for IBM PC compatibles. *Behaviour Research Methods, Instruments and Computers. 20 (2),* 206 217.

Schneider, W. & Shriffrin, R. M. (1977). Controlled an Automatic Human Information Processing: I. Detection, Search and Attention. *Psychological Review, 84(1),* 1-66.

Sergent, J. (1982). The Cerebral Balance of Power: Confrontation or Cooperation? *Journal of Experimental Psychology: Human Perception and Performance, 8 (2),* 253-272.

Shedden, J. M. & Reid, G. S. (submitted). Directed attention to global or local levels of compound objects: Identification of ignored local distractors.

Springer, S. P & Deutsch, G. D. (1993). Left Brain, Right Brain. New York: W. H. Freeman and Company.

Steenhuis, R. E. & Bryden, M. P. (1989). Different dimensions of handedness that relate to skilled and unskilled activities. *Cortex, 25*, 289-304.

Teuber, H. L. (1975). Recovery of function after brain injury in man. *In.* R. Porter & D. W. Fitzsimmons (eds.). Outcome of Severe Damage to the Nervous System. CIBA Foundation Symposium, 34. Amsterdam: Elsevier.

Wurtz, R. H., Goldberg, M. E. & Robinson, D. L. (1980). Behavioural modulation of visual responses in the monkey: Stimulus selection for attention and movement. *Progress in Psychobiology, Physiology, Psychology 9,* 43-83.

TABLE 1: Mean Response Times from Experiments 1a and 1b

		LVF/RH	RVF/LH
BOX DISTRACTORS	GLOBAL	538 (57)	540 (60)
	LOCAL	556 (45)	544 (54)
DIGIT DISTRACTORS	GLOBAL	565 (44)	573 (54)
	LOCAL	594 (50)	588 (67)

Table 1: Mean RTs and standard deviations (in brackets) for the box and digit distractor conditions.

TABLE 2: Mean Response Times from Experiments 2a and 2b

			LVF/RH	RVF/LH
BOX DISTRACTOR	FIXED	GLOBAL	538 (42)	522 (27)
		LOCAL	529 (19)	535 (38)
	SWITCHING	GLOBAL	520 (29)	525 (17)
		LOCAL	537 (21)	526 (24)
DIGIT DISTRACTOR	FIXED	GLOBAL	524 (40)	535 (57)
		LOCAL	533 (63)	545 (52)
	SWITCHING	GLOBAL	540 (63)	528 (58)
		LOCAL	562 (54)	544 (45)

Table 2: Mean RTs and standard deviations (in brackets) for the conditions in which attention was Fixed on level and visual field and in which attention Switched among levels and visual fields.

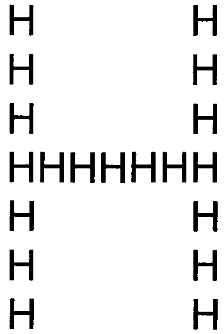


Figure 1. Stimuli used in Navon's experiments. These figures are used routinely in studies of global-local processing. They exhibit the hierarchy evident in many natural objects but preclude the use of familiarity or knowledge in identification of stimuli at the levels.

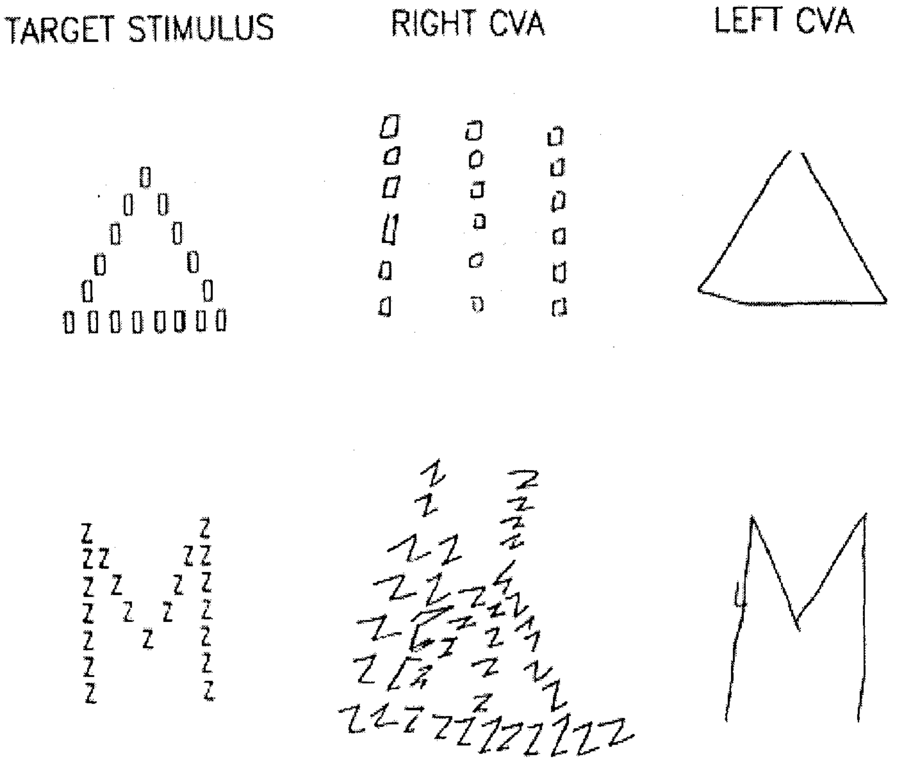


Figure 2. Patients with right hemisphere damage recalled only the local features of the original stimulus while those with left hemisphere lesions recalled only the global form (Delis, Robertson & Efron, 1986).

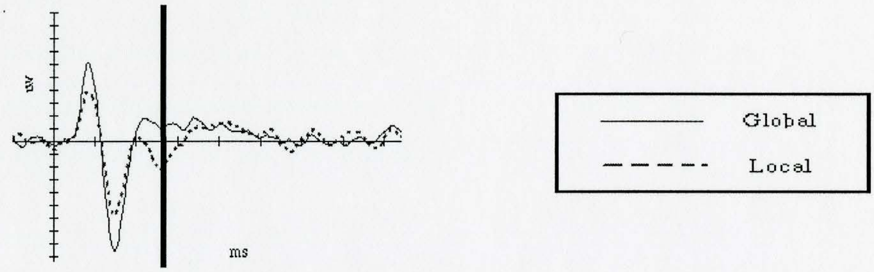


Figure 3a. Waveforms illustrate the temporal nature of on-going cognitive processes at one critical location.

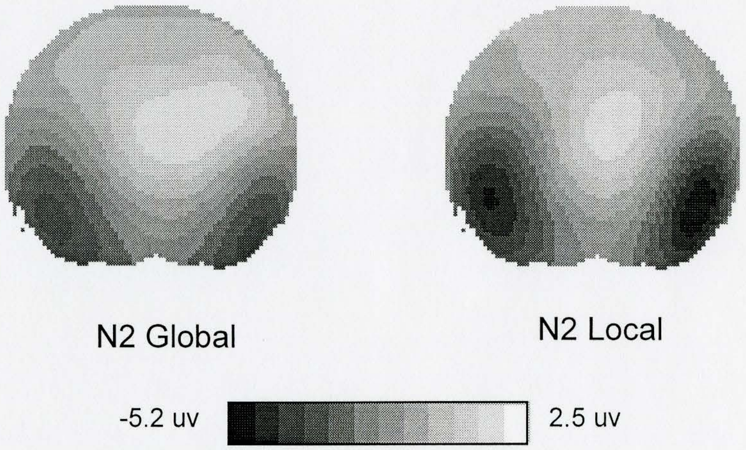
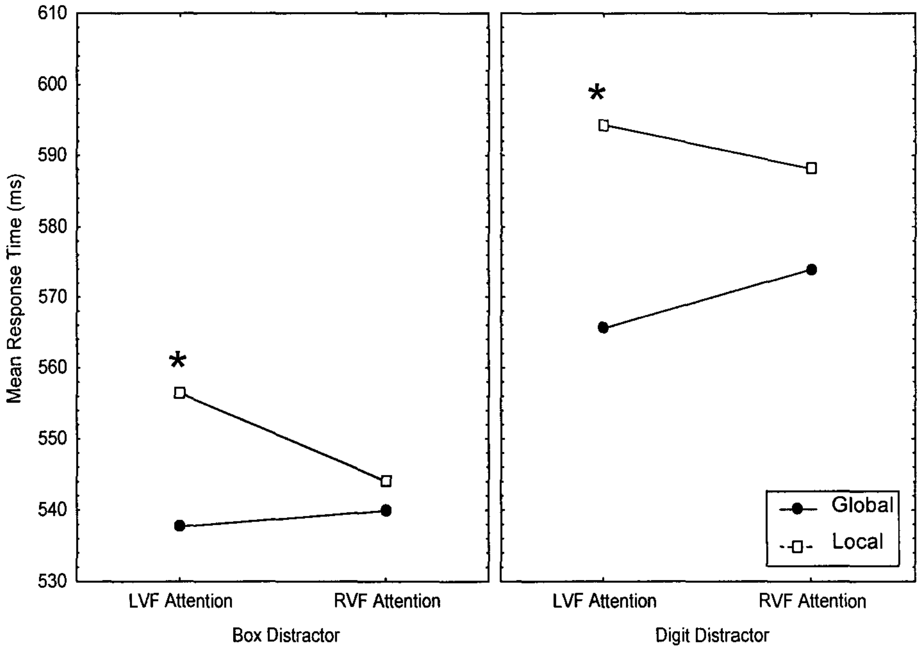


Figure 3b. Topologies illustrate the spatial distribution of positive and negative deflections at a particular time point. Relative voltages are indicated for each set of topologies.

In this example, a comparison of the waveform and topologies reveals that at the time point indicated, attention to a global stimulus elicits less negativity over the posterior brain than attention to a local stimulus.



(5a) (5b)

Figure 4. Response times for box versus digit distractor conditions

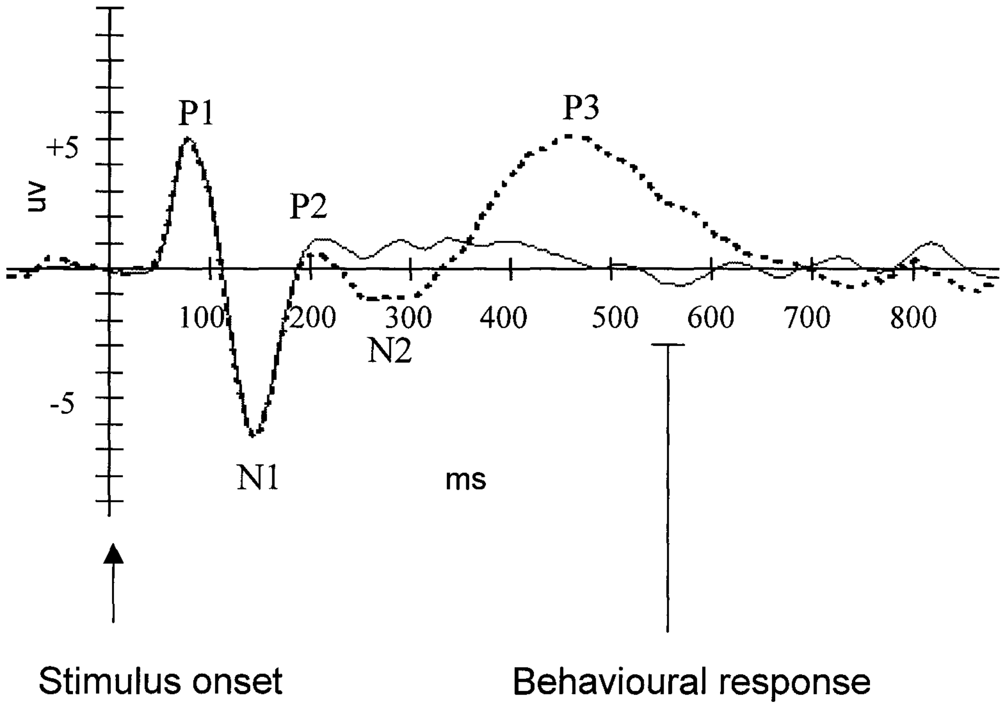


Figure 5. This sample waveform indicates the standard nomenclature for each of the visual ERP components. Stimulus onset and behavioural response are indicated to facilitate an appreciation of the temporal context in which these components appear.

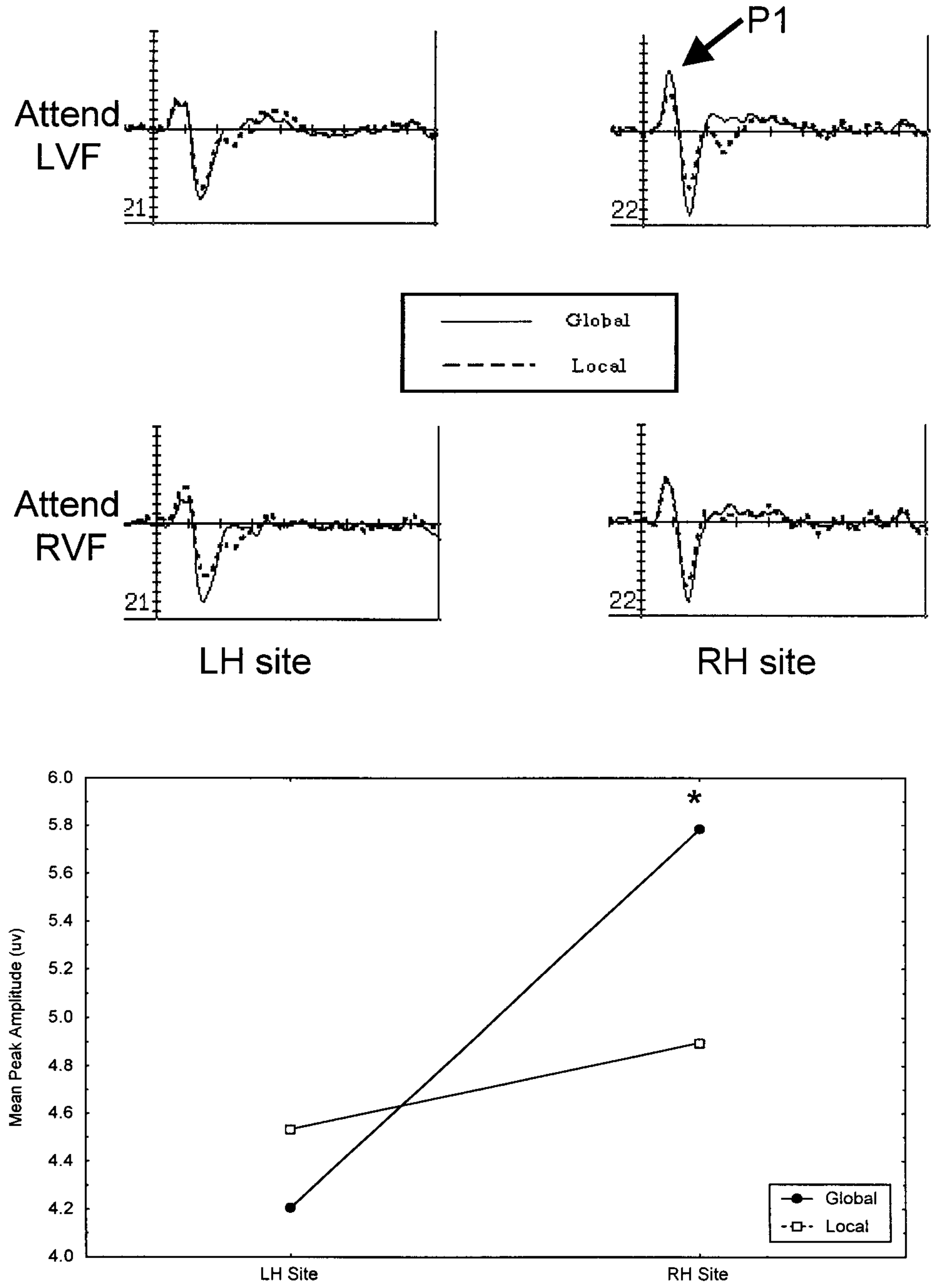


Figure 6a. *Top panel:* Waveforms at P1 for box distractors. *Bottom Panel:* Channel X Level interaction.

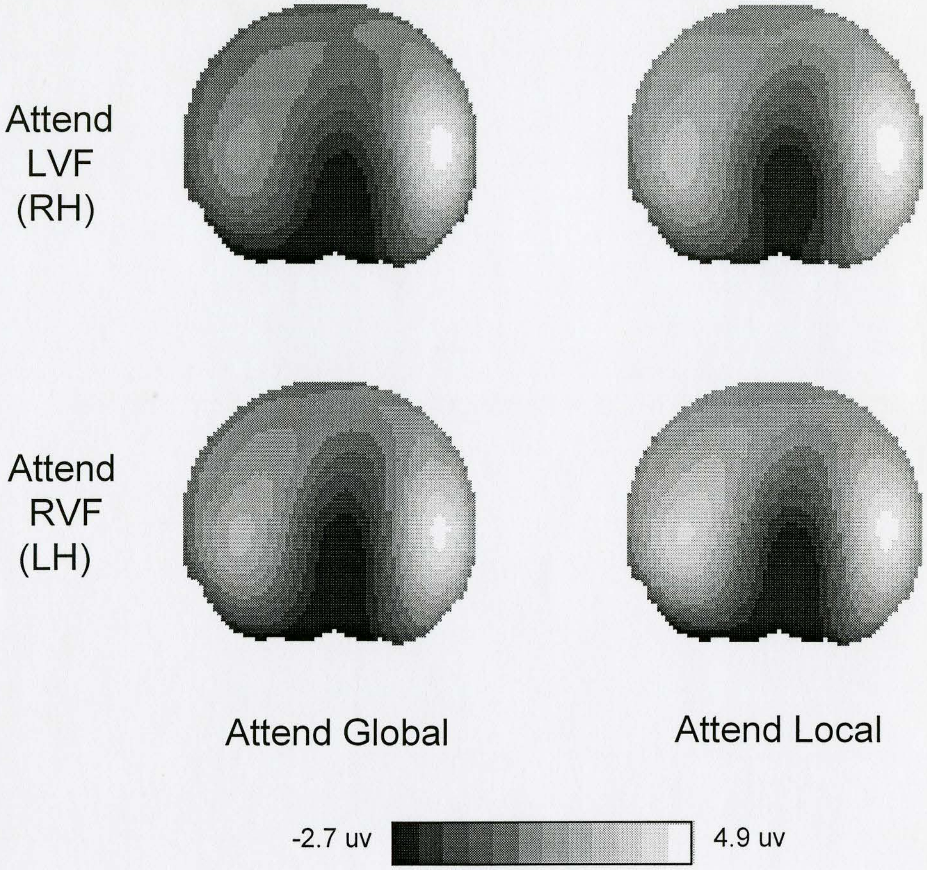


Figure 6b. Posterior topologies of P1 peak amplitudes (85 ms) in the box distractor condition.

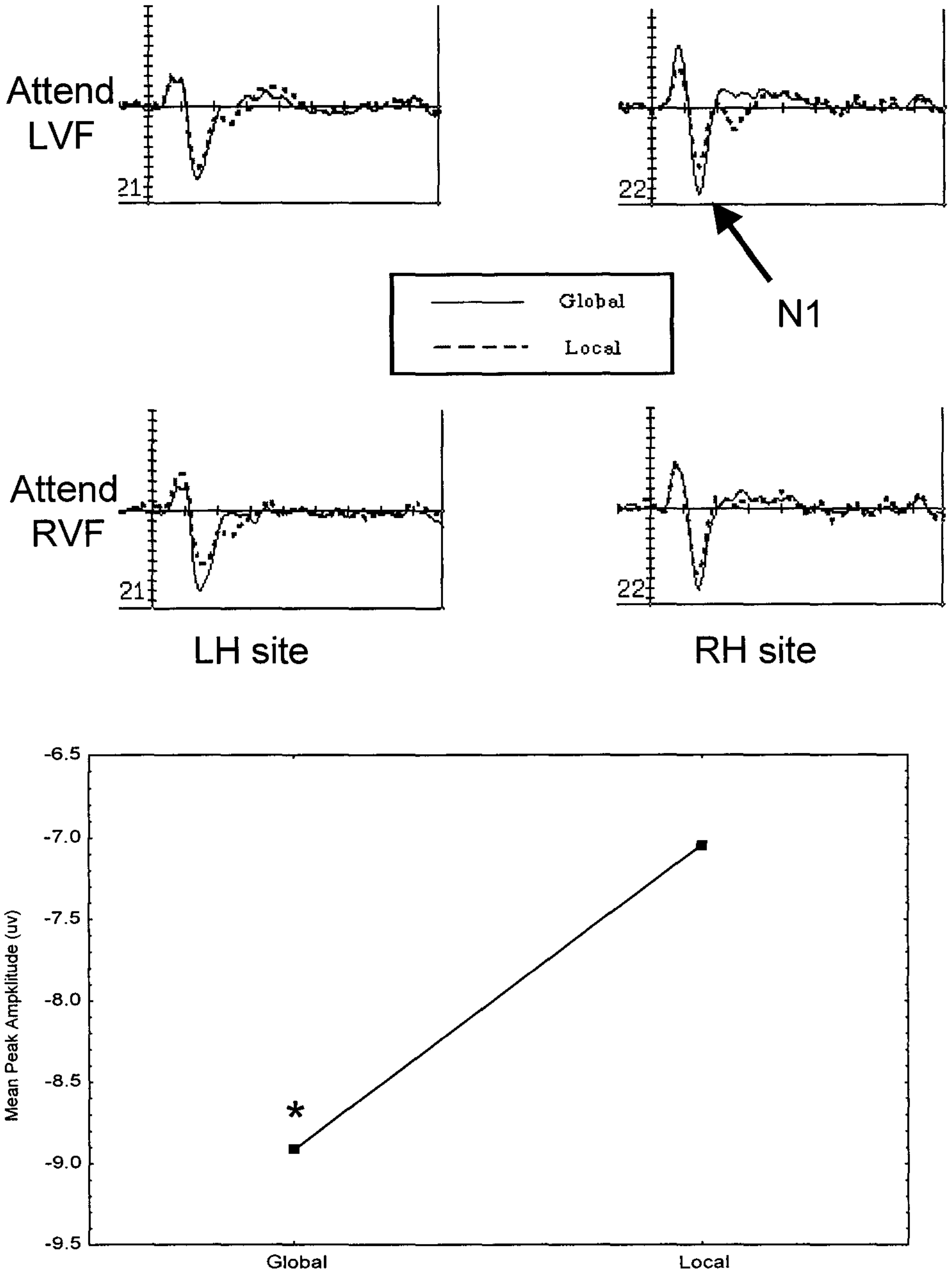


Figure 7a. *Top panel:* Waveforms at N1 for box distractors. *Bottom Panel:* Main effect of Level.

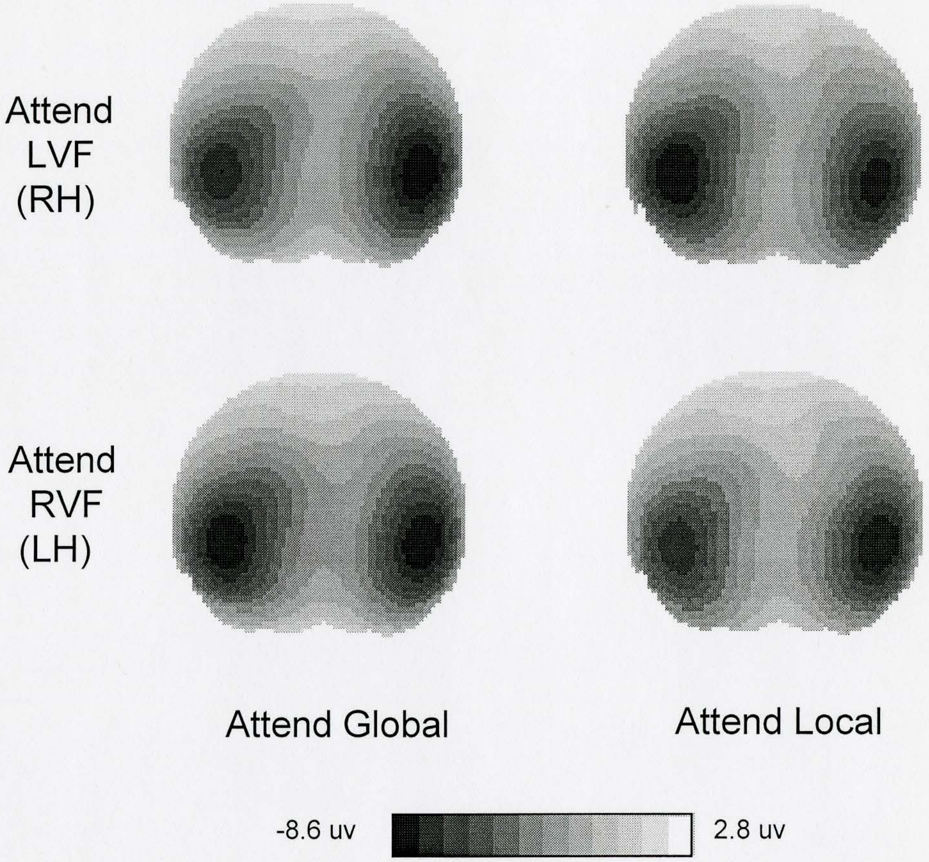


Figure 7b. Posterior topologies of N1 peak amplitudes (145 ms) in the box distractor condition.

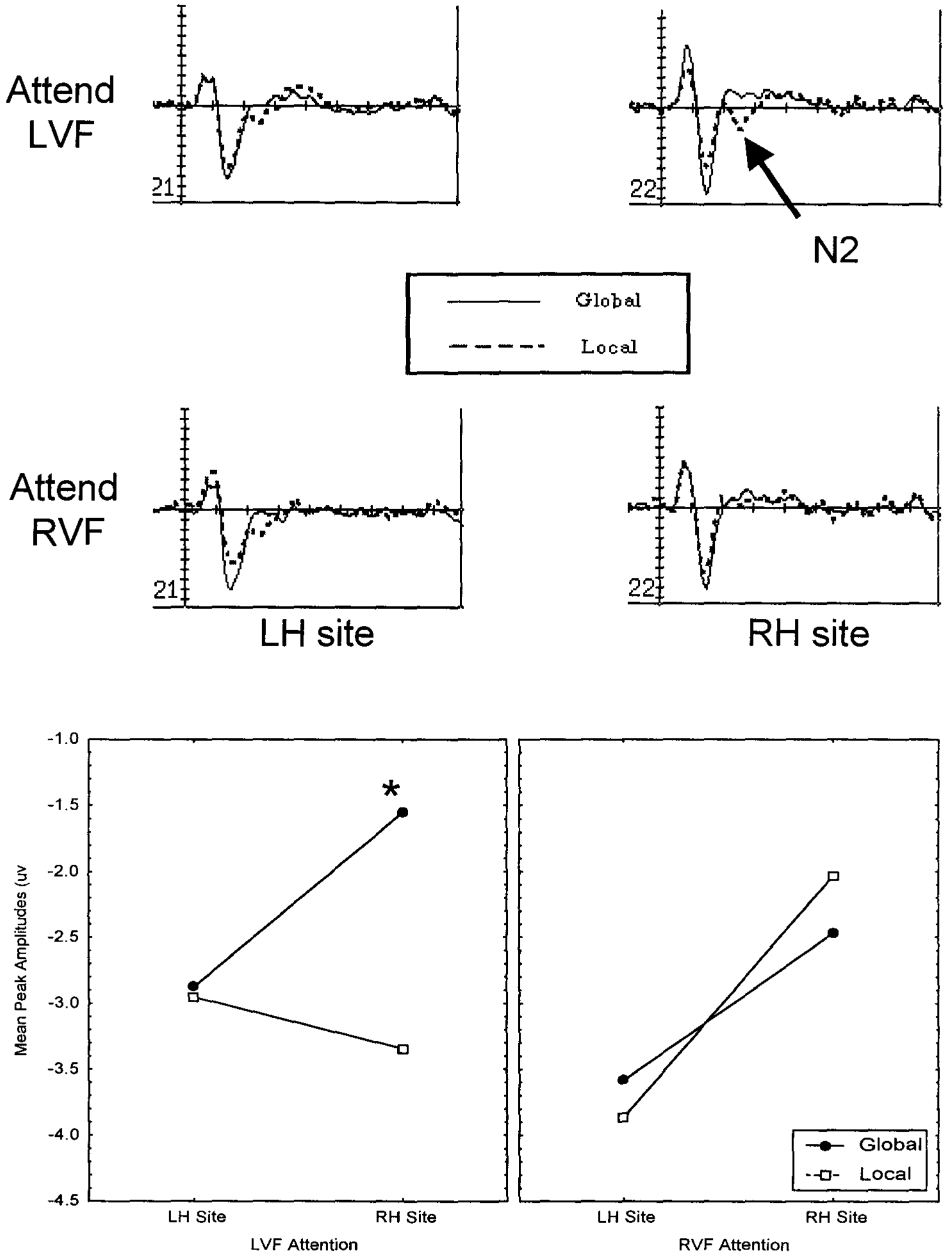


Fig 8a. *Top panel:* N2 component for the box distractor condition. *Bottom Panel:* Channel X Level X Visual Field interaction.

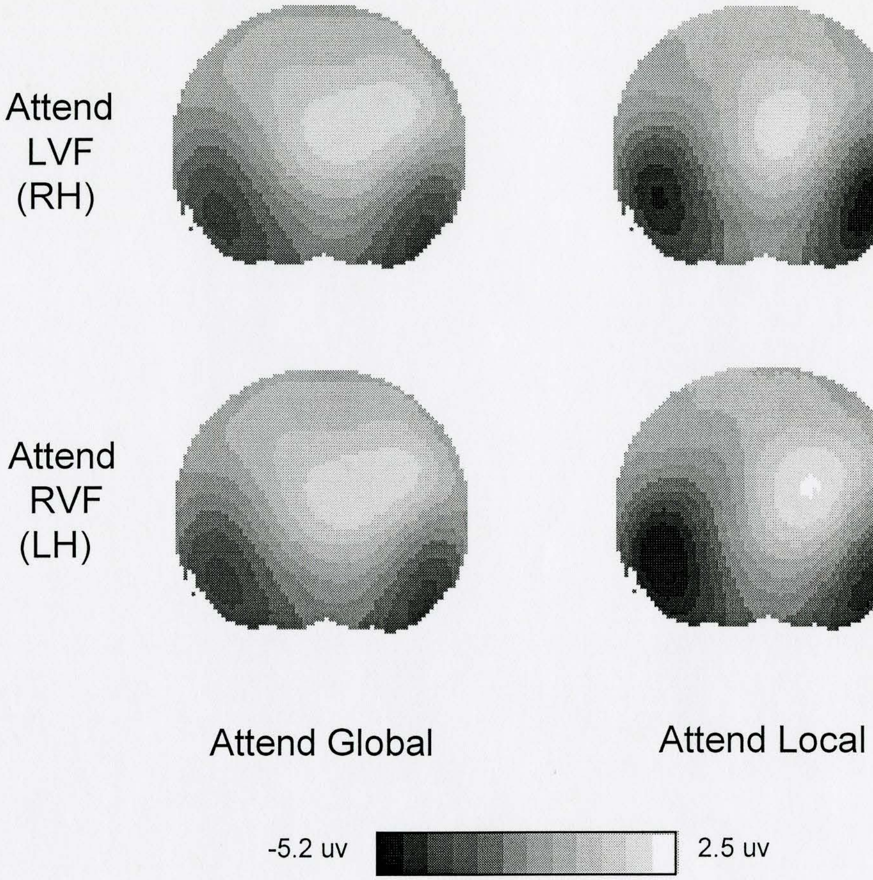


Figure 8b. Posterior topologies of N2 peak amplitudes (245 ms) in the box distractor condition.

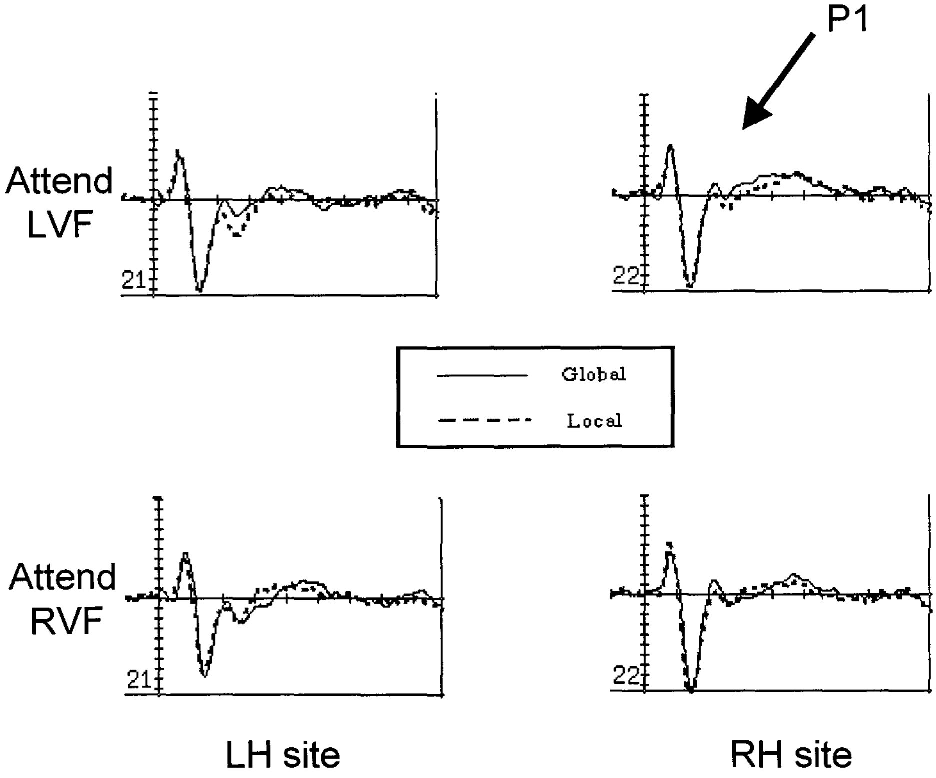


Figure 9a. *Top panel:* P1 component for the digit distractor condition. There were no significant amplitude differences at P1 when distractors were digits.

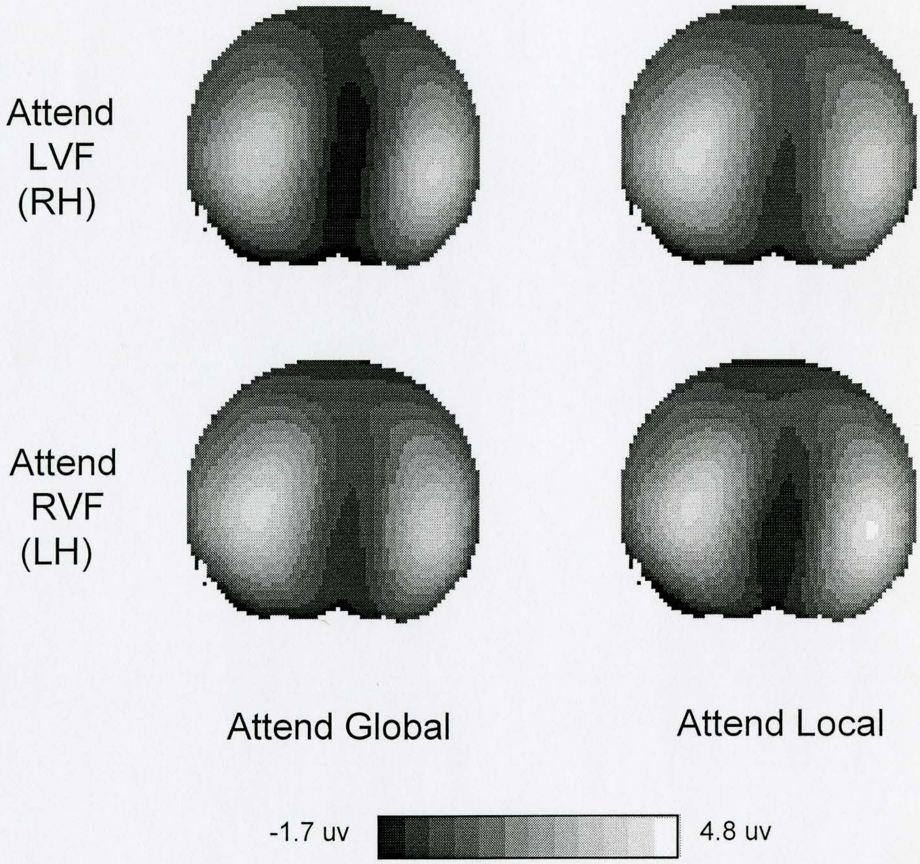


Figure 9b Posterior topologies of P1 peak amplitudes (85 ms) in the digit distractor condition.

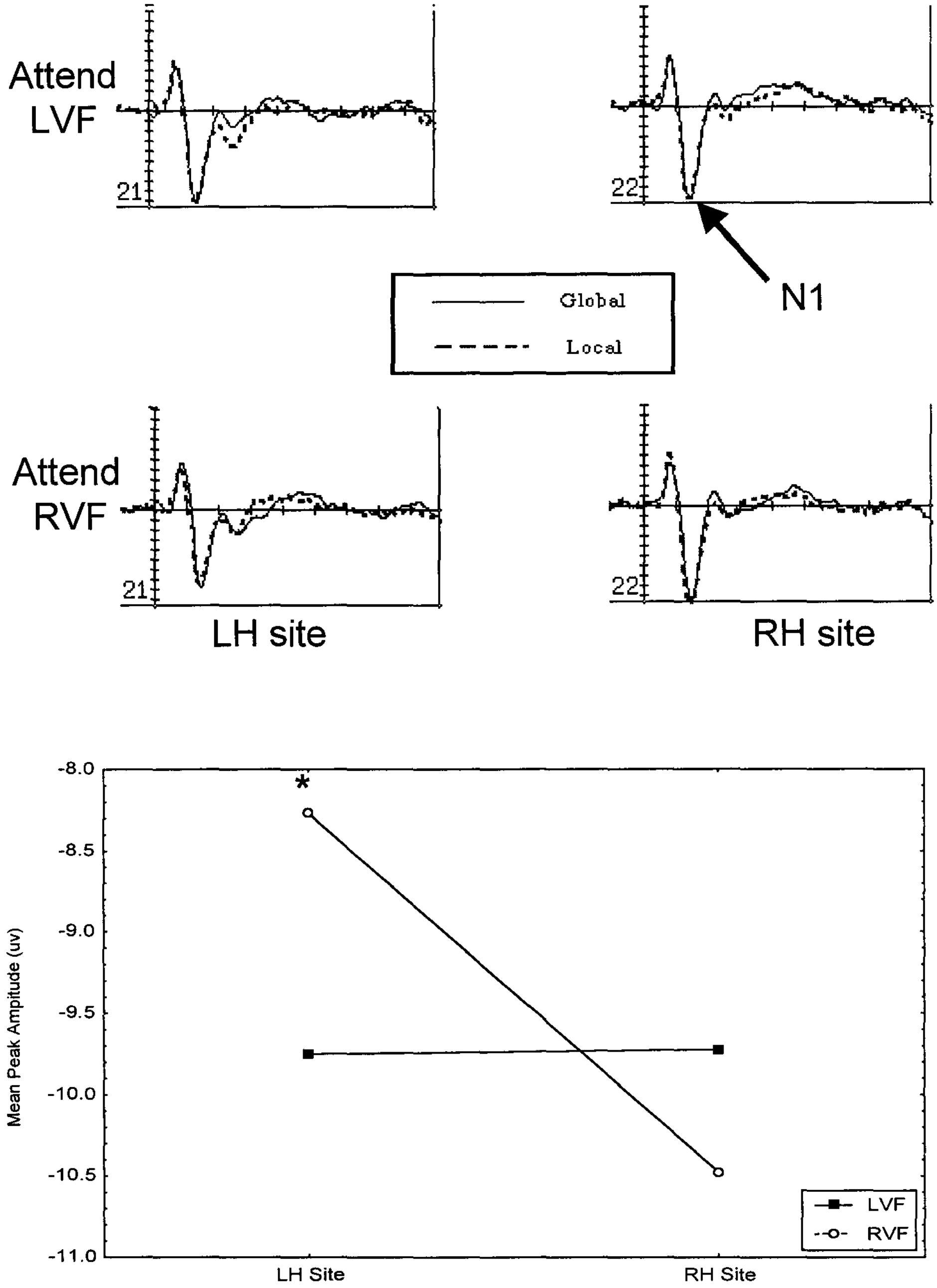


Figure 10a *Top panel:* N1 component for the digit distractor condition. *Bottom Panel:* Channel X Visual Field interaction.

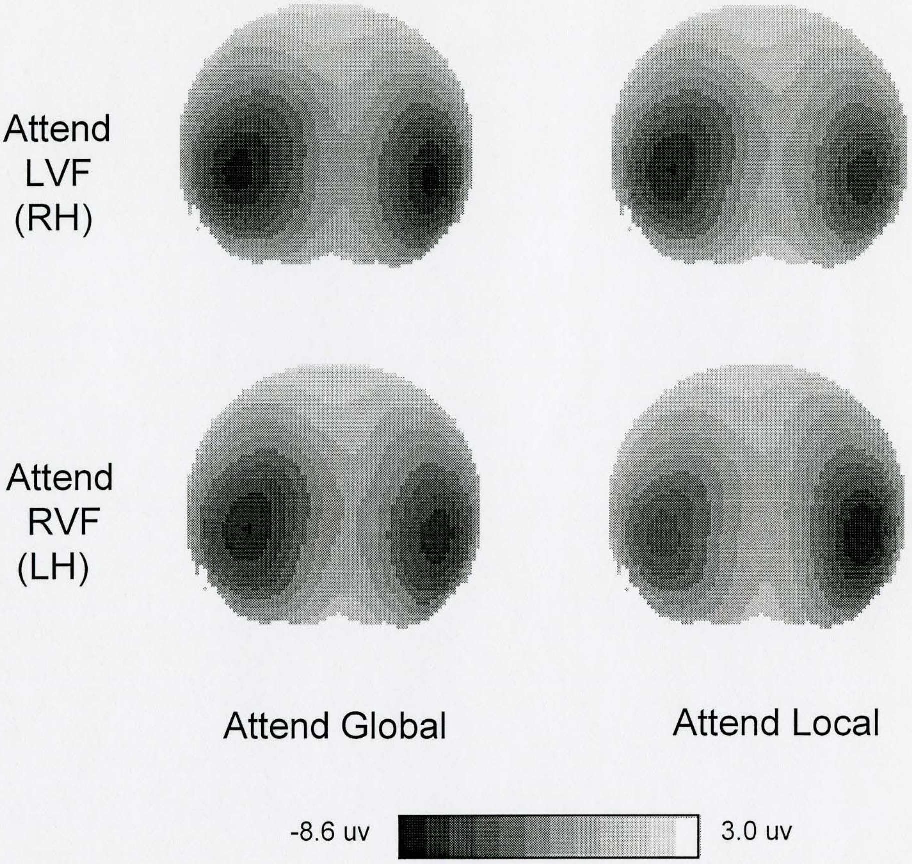


Figure 10b. Posterior topologies of N1 peak amplitudes (145 ms) in the digit distractor condition.

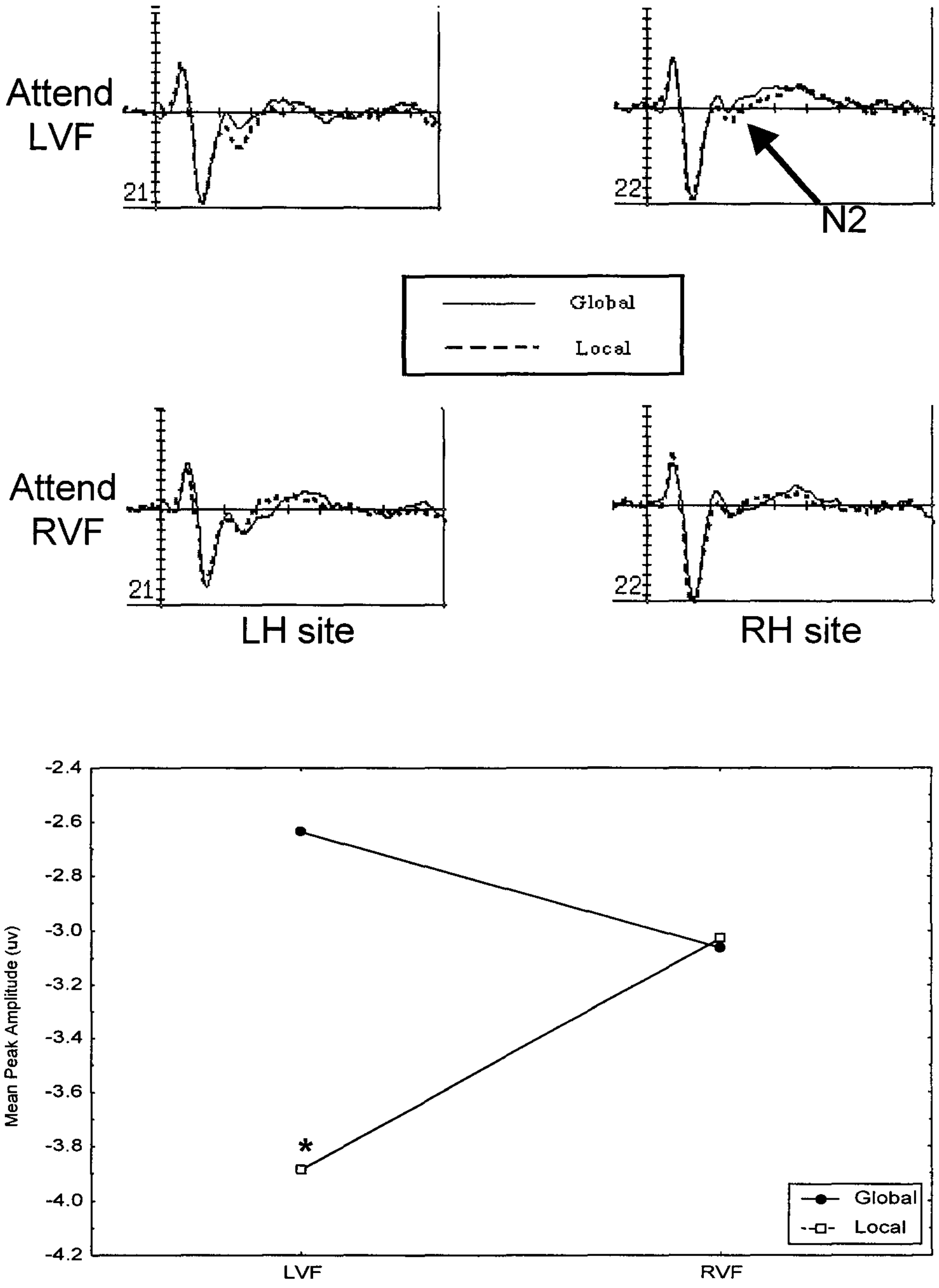


Figure 11a. *Top panel:* N2 component for the digit distractor condition. *Bottom Panel:* Level X Visual Field interaction.

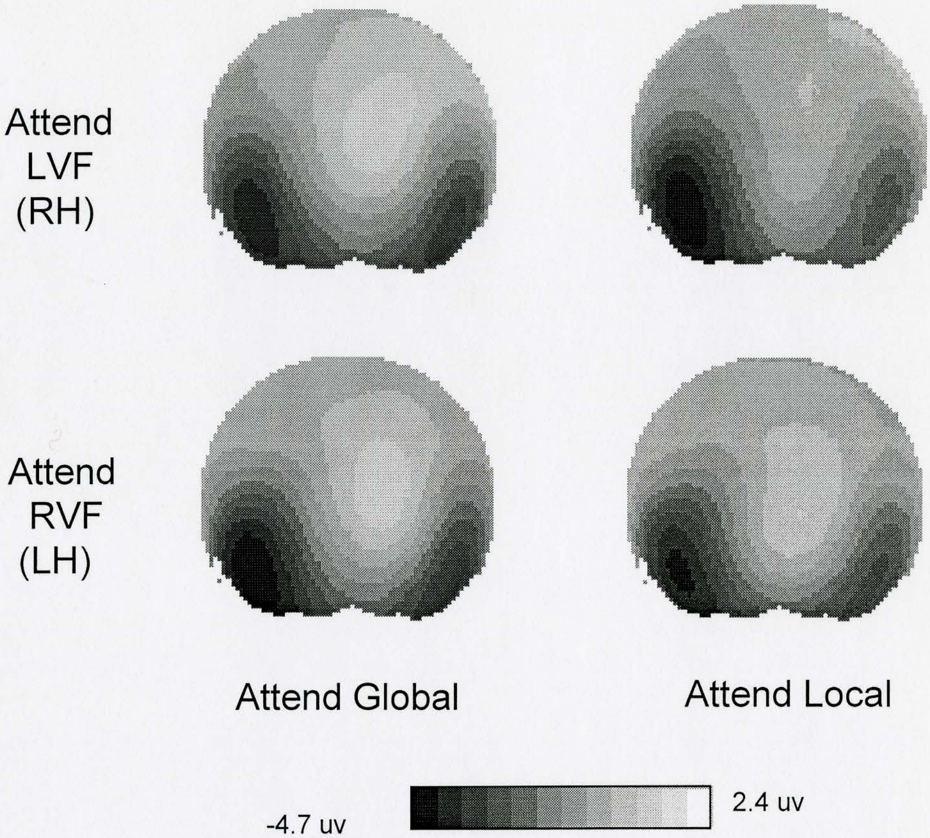


Figure 11b Posterior topologies of N2 peak amplitudes (255 ms) in the digit distractor condition.

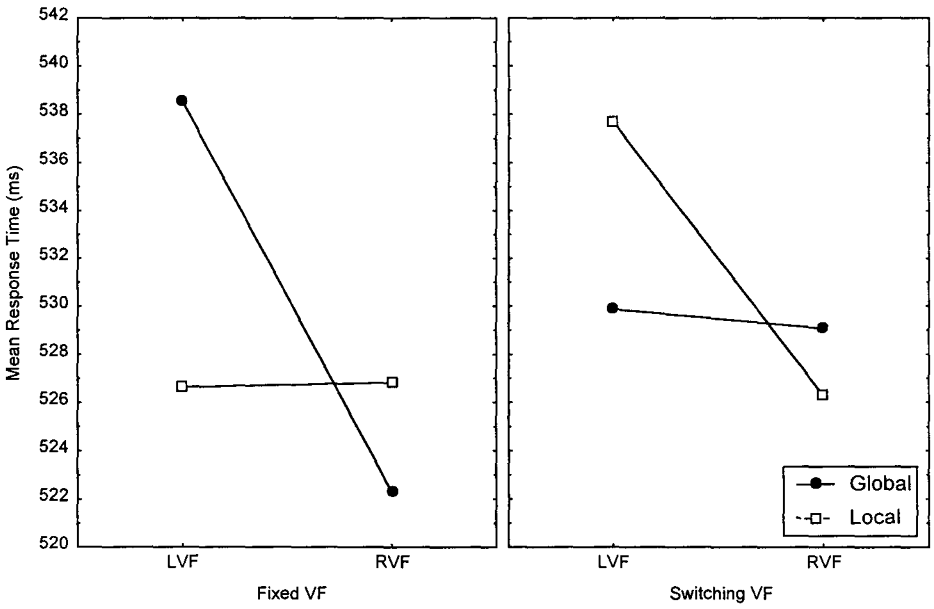


Figure 12a. Mean RT Fixed and Switching VF conditions; Visual Field X Level interaction; distractors were boxes. Although differences between pairs of means were not significant, this pattern is of theoretical interest.

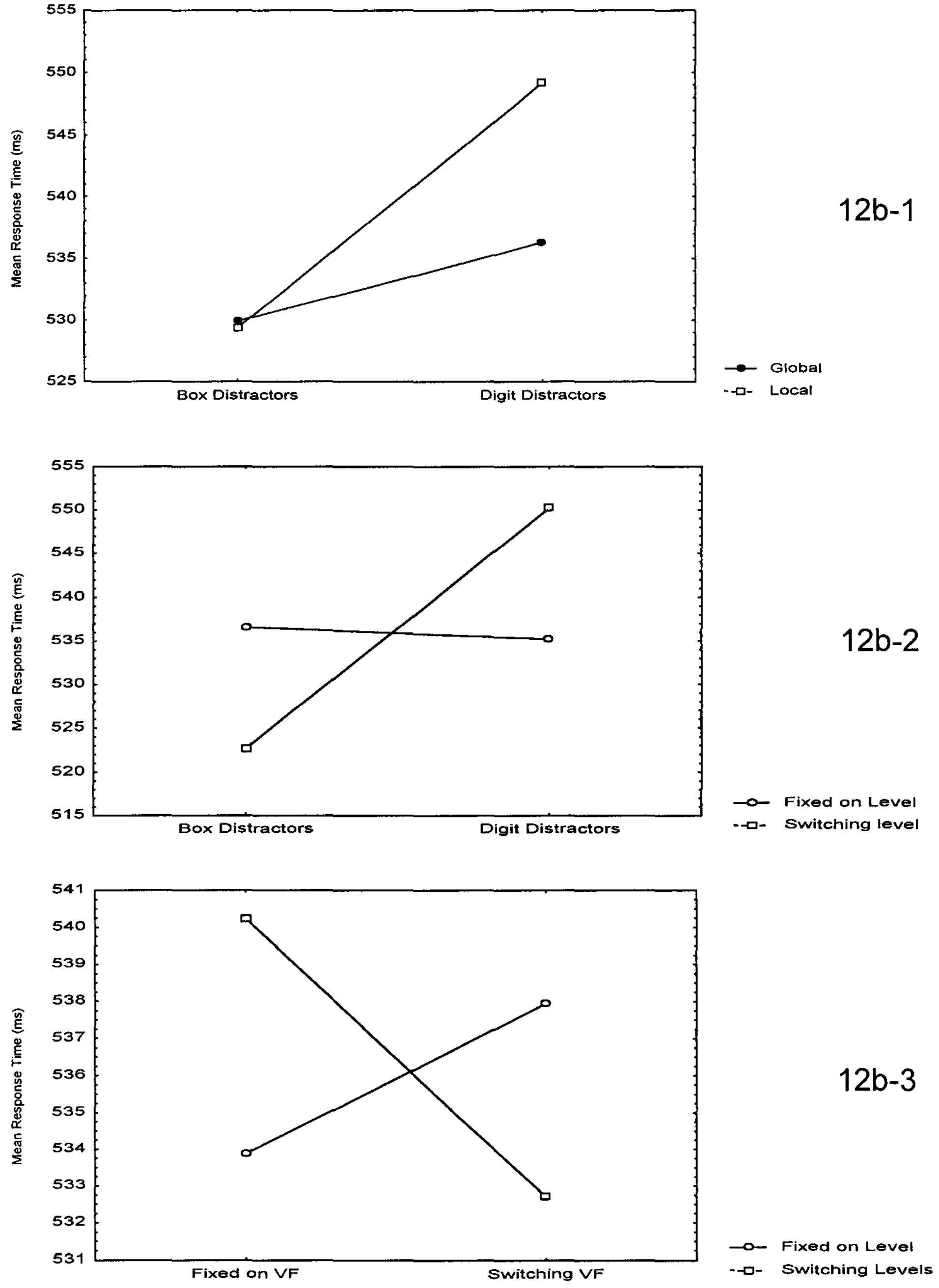


Figure 12b. Mean Response Time data in Fixed vs. Switching conditions for box versus digit distractors.

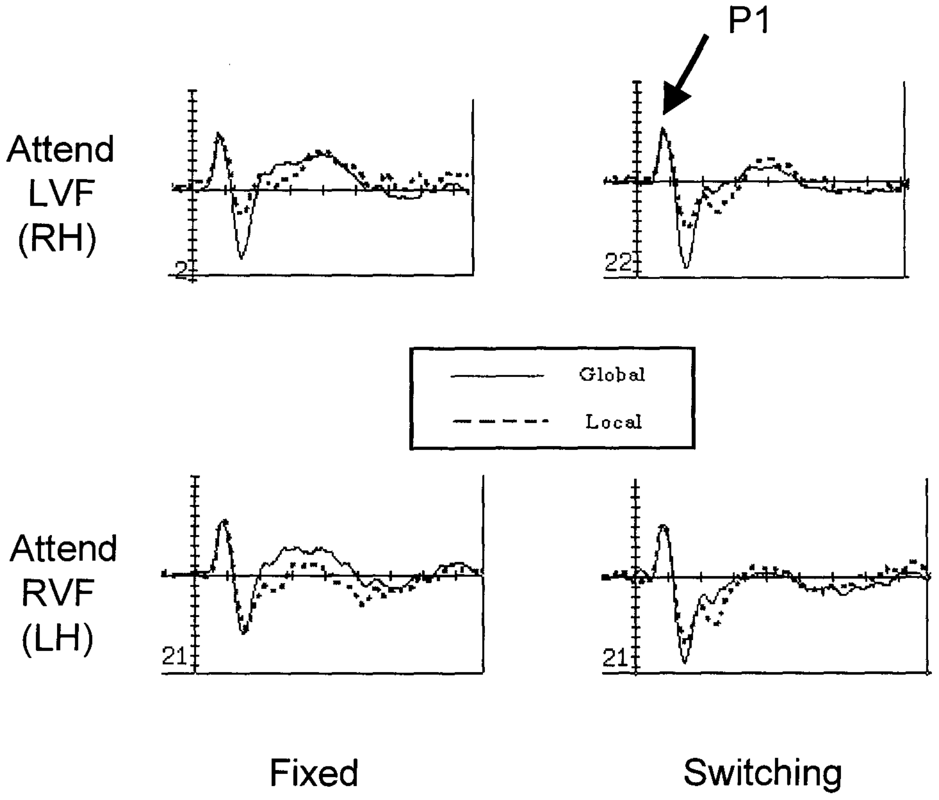


Figure 13a. P1 components arising from fixed and switching attention in the box distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

Note that the layout of the figures has changed: only the hemisphere receiving the attended stimulus is represented here and in subsequent figures.

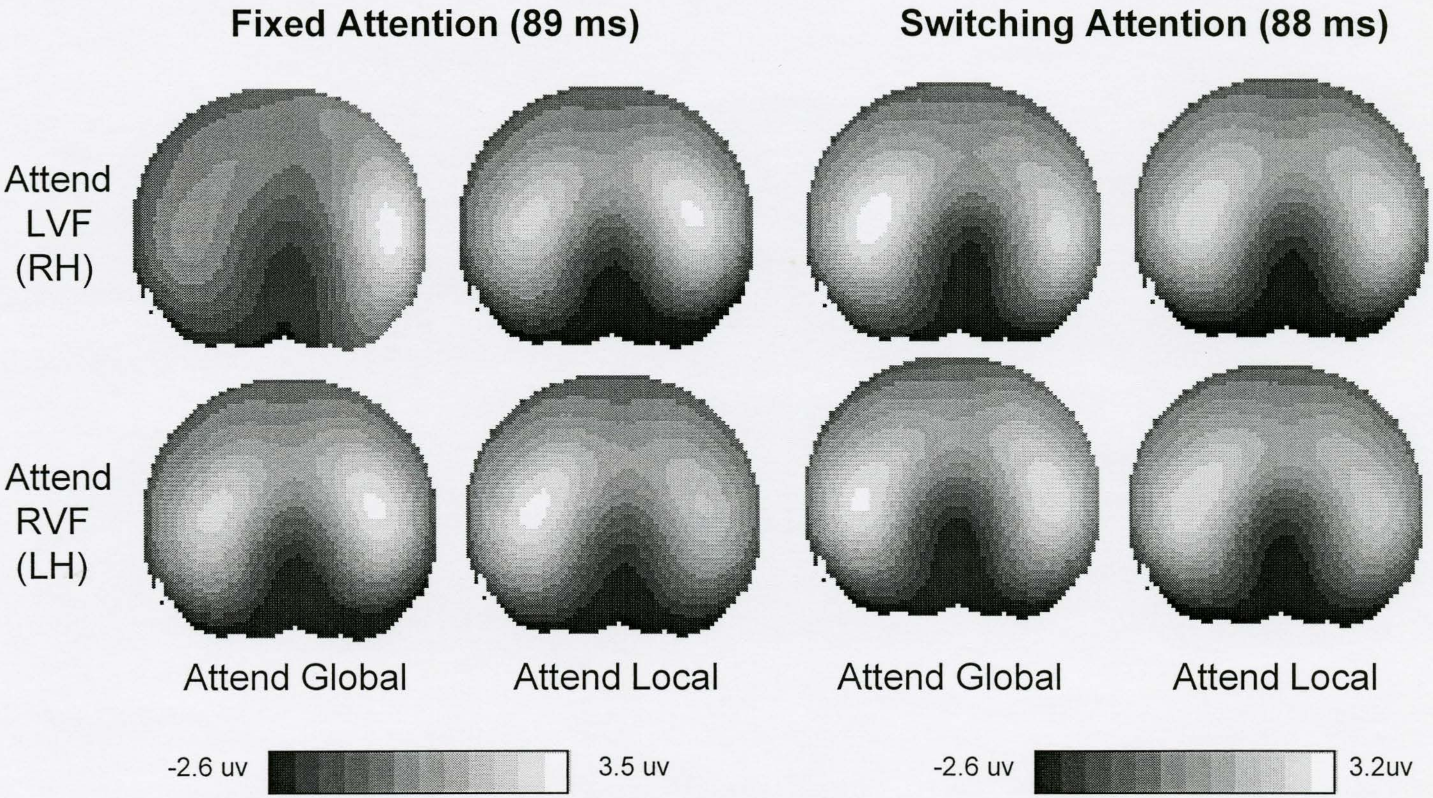
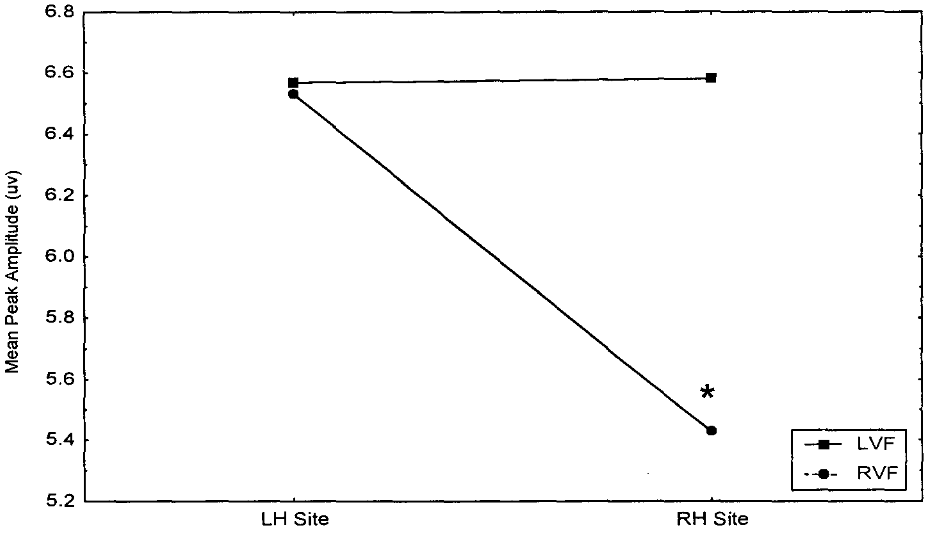


Figure 13b. Posterior topologies representing the spatial distributions of the P1 component in the Fixed versus Switching conditions. Distractors are boxes.

P1-Fixed: Box distractors
Channel X Visual Field Interaction



P1-Switching: Box distractors

There were no significant differences at P1 in the Switching conditions.

Figure 13c. P1 amplitudes in the Fixed and Switching conditions; distractors are boxes.

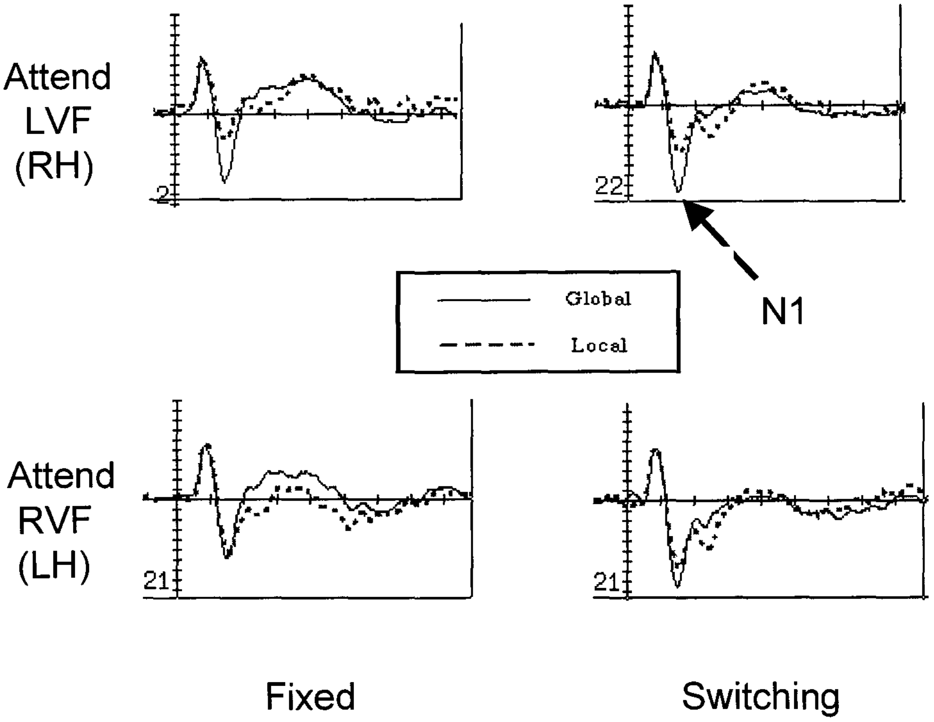
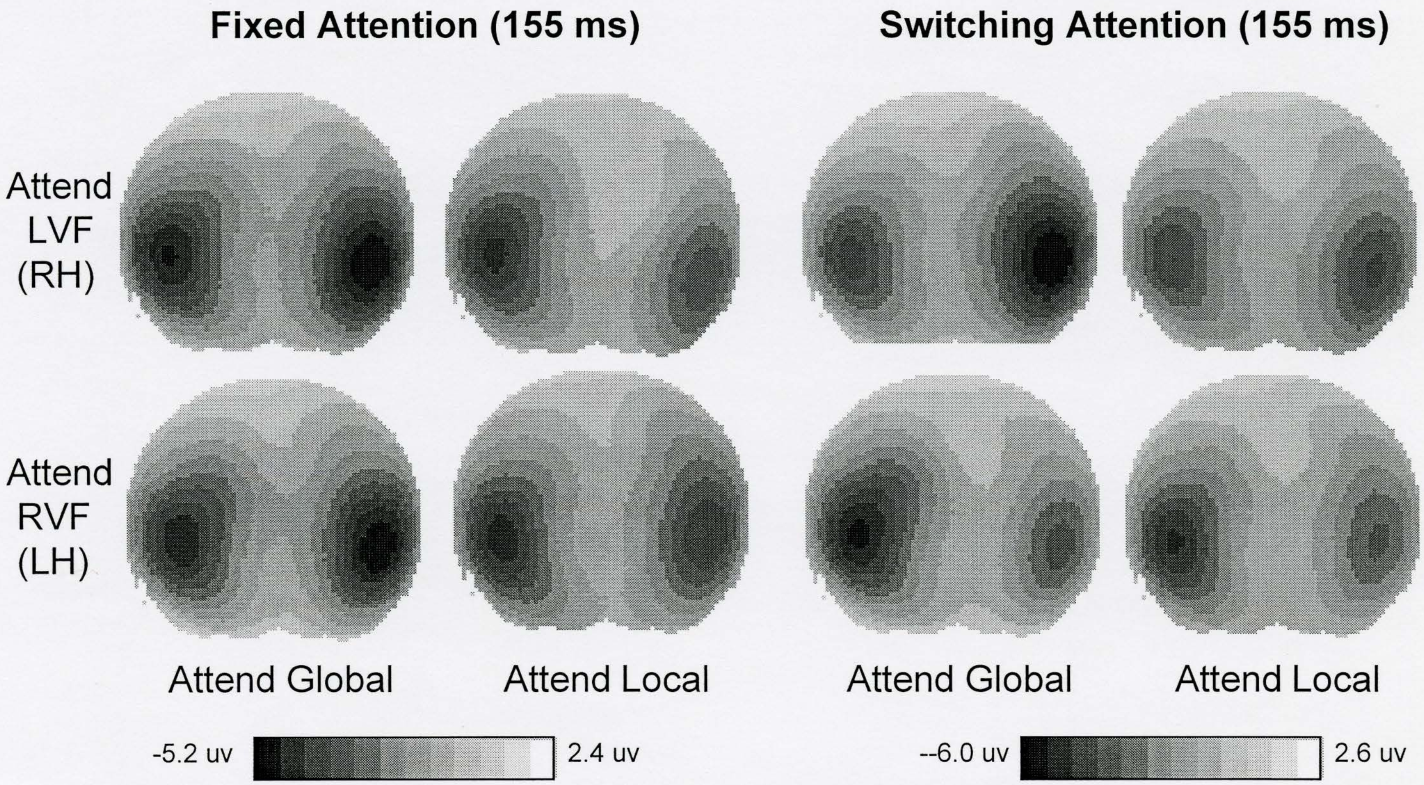


Figure 14a. N1 components arising from fixed and switching attention in the box distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

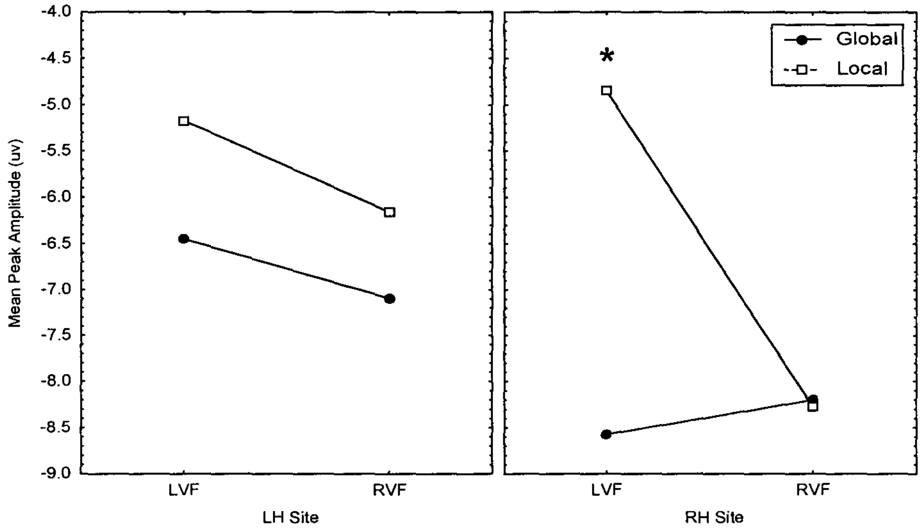


Fixed Attention (155 ms)

Switching Attention (155 ms)

Figure 14b. Posterior topologies representing the spatial distributions of the N1 component in the Fixed versus Switching conditions. Distractors are boxes.

N1-Fixed: Box distractors
Channel X Visual Field X Level interaction



N1-Switching: Box distractors
Level main effect

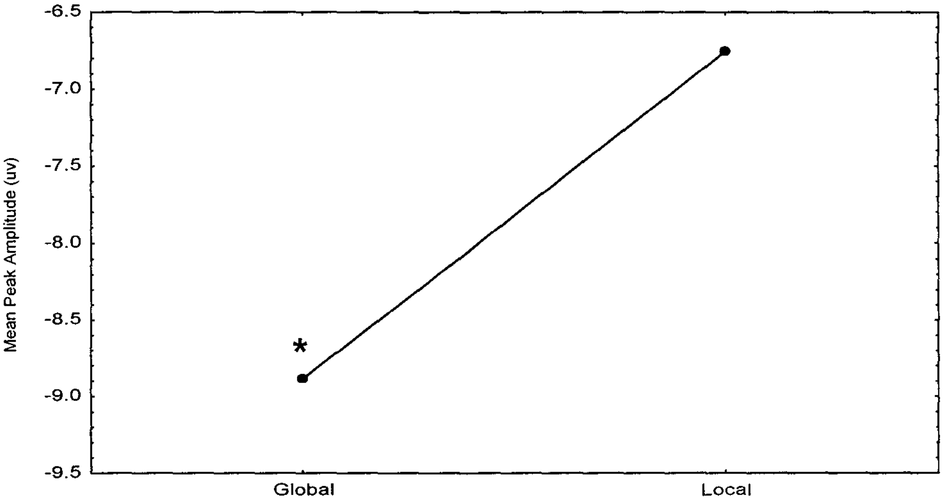


Figure 14c. N1 amplitudes in the Fixed and Switching conditions; distractors are boxes.

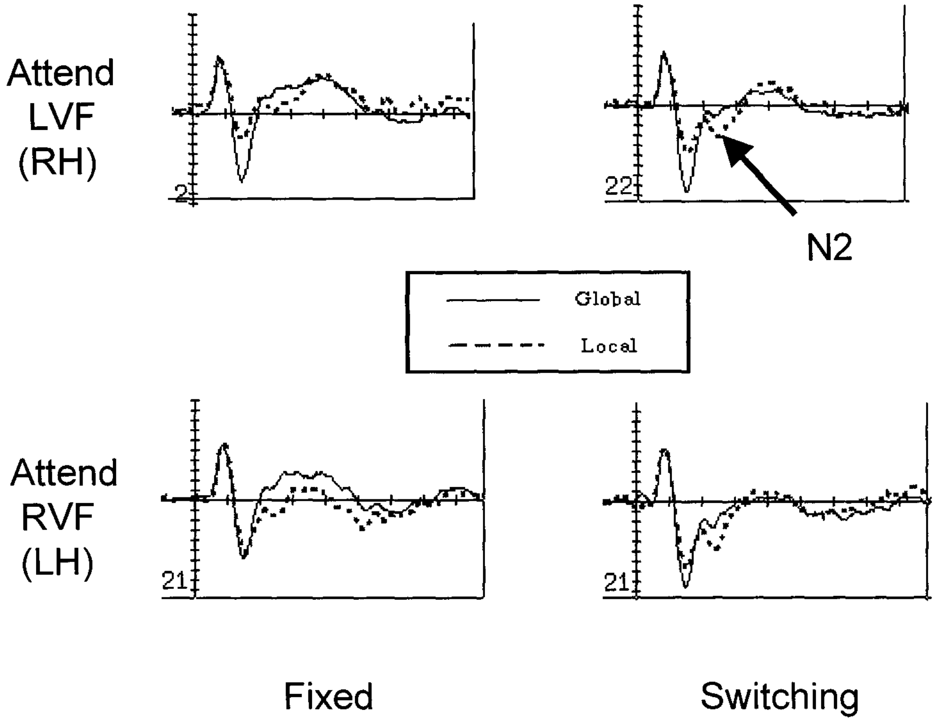


Figure 15a. N2 components arising from fixed and switching attention in the box distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

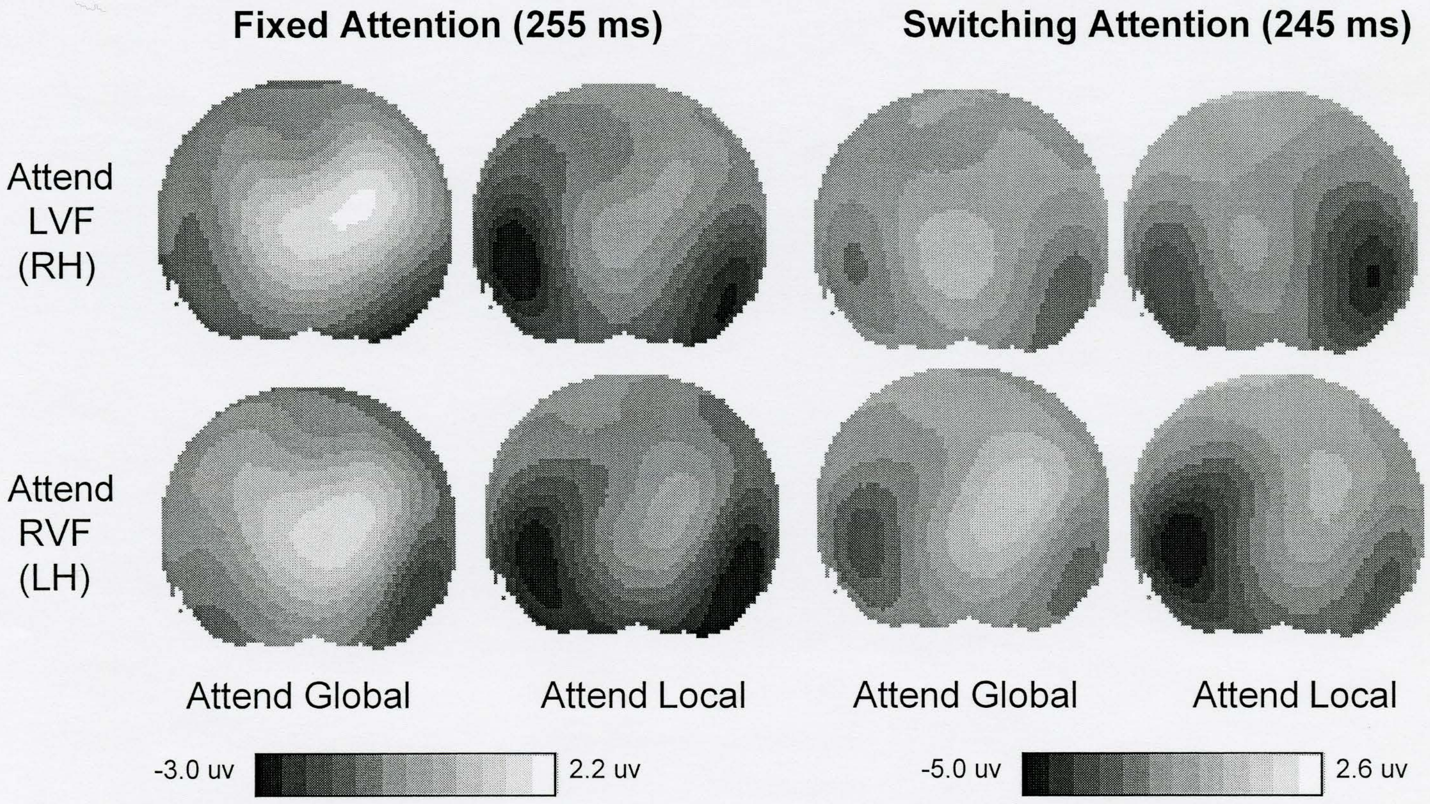
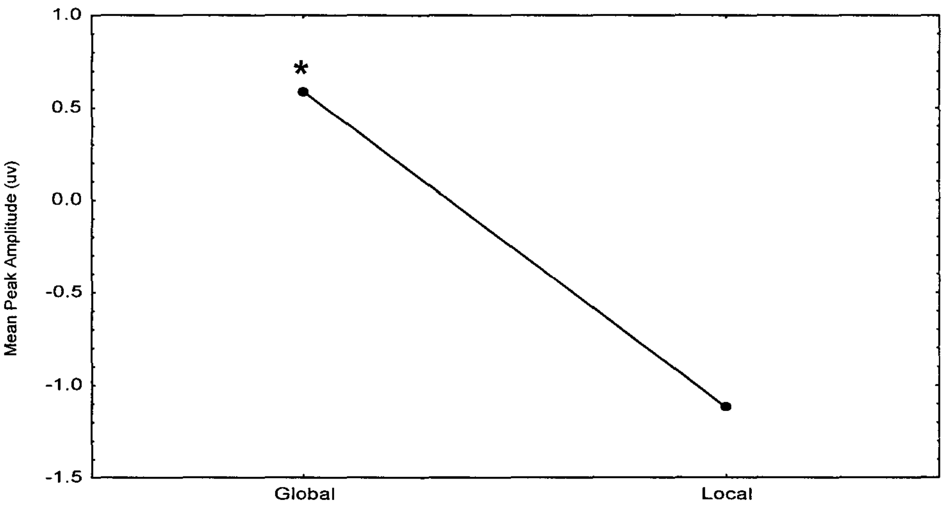


Figure 15b. Posterior topologies representing the spatial distributions of the N2 component in the Fixed versus Switching conditions. Distractors are boxes.

N2-Fixed: Box distractors
Level main effect



N2-Switching: Box distractors
Channel x Visual Field interaction

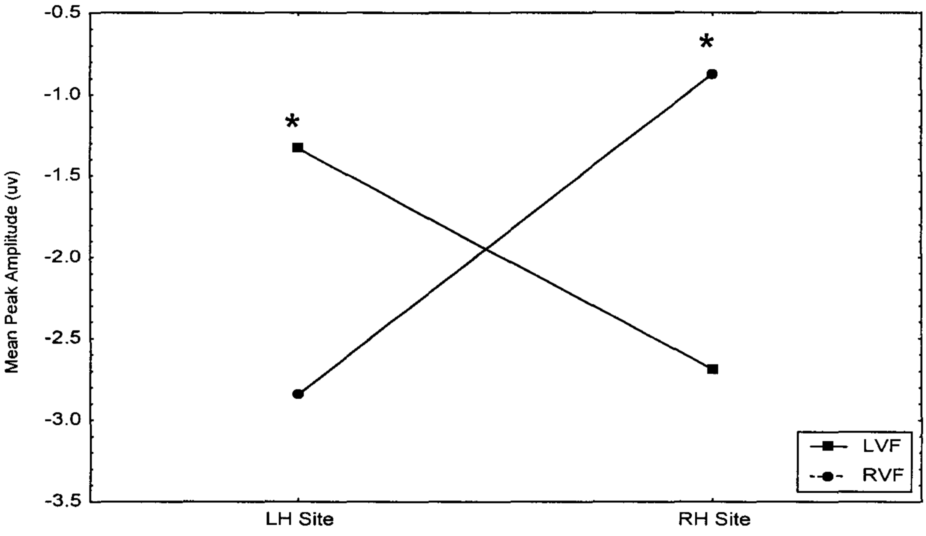


Figure 15c. N2 amplitudes in the Fixed and Switching conditions; distractors are boxes.

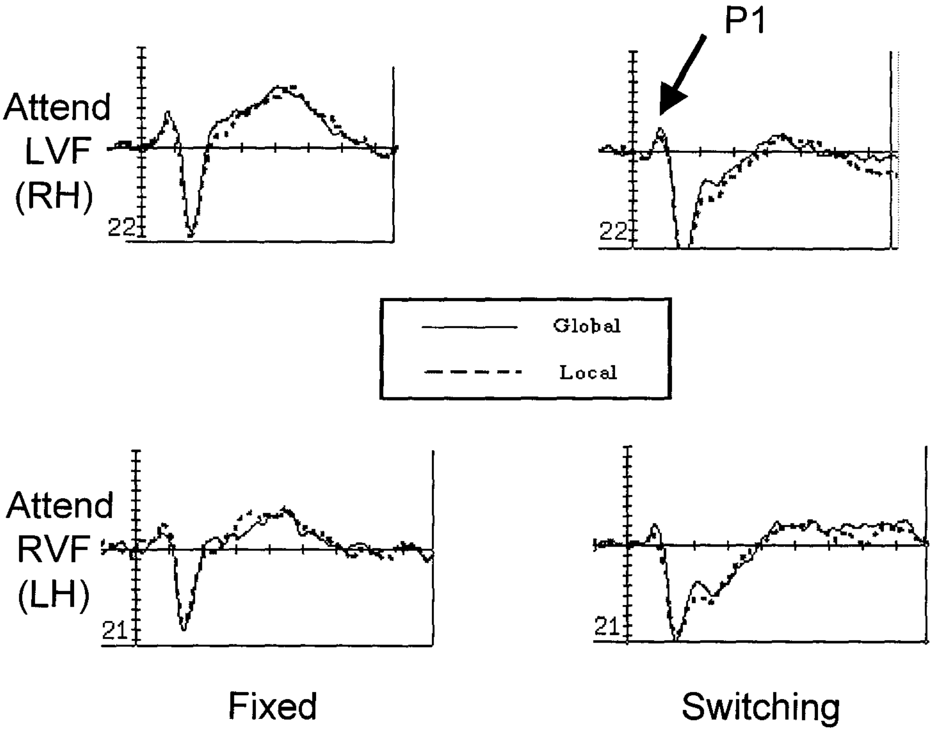


Figure 16a. P1 components arising from fixed and switching attention in the digit distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

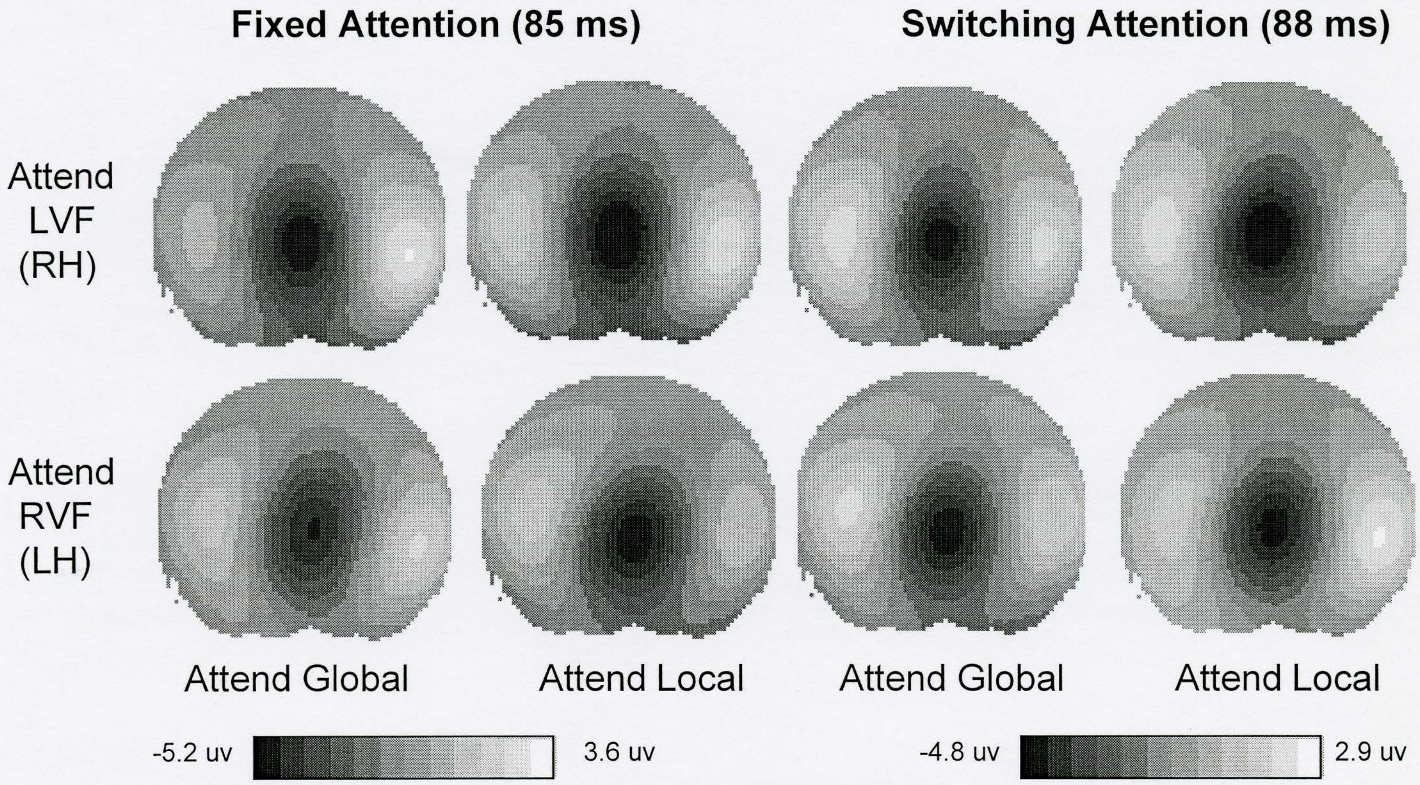


Figure 16b. Posterior topologies representing the spatial distributions of the P1 component in the Fixed versus Switching conditions. Distractors are digits.

P1-Fixed: Digit distractors

There were no significant effects at P1 when attention was Fixed and distractors were digits.

P1-Switching: Digit distractors

Channel x Visual Field interaction

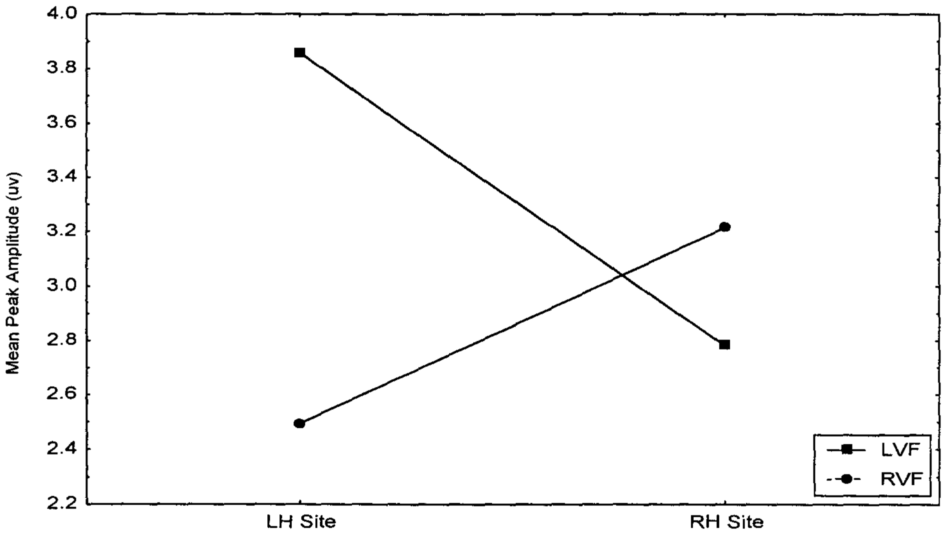


Figure 16c. P1 amplitudes in the Fixed and Switching conditions; distractors are digits.

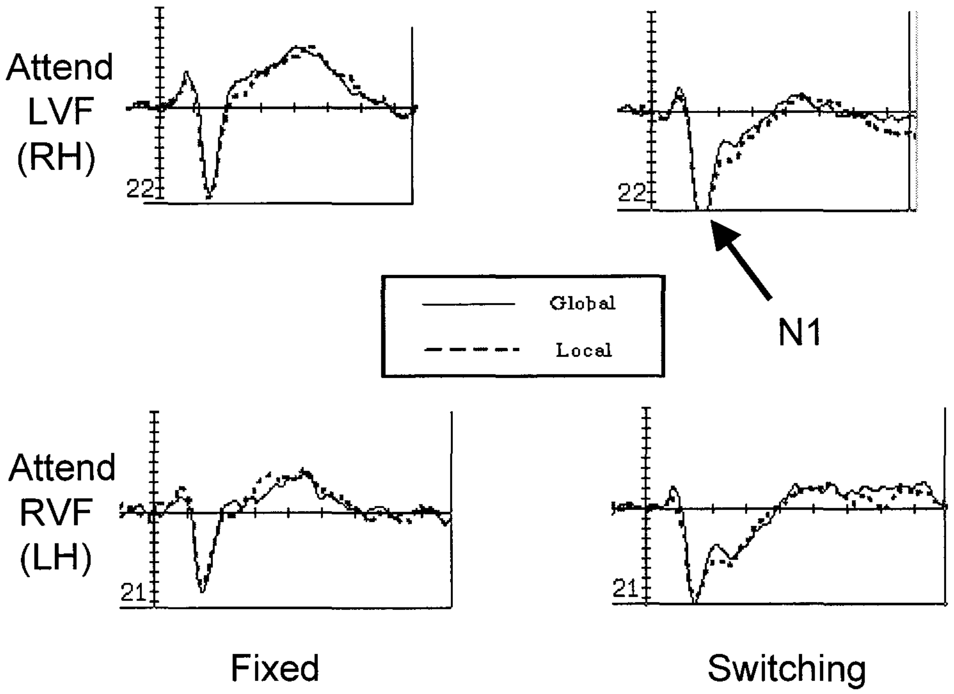


Figure 17a. N1 components arising from fixed and switching attention in the digit distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

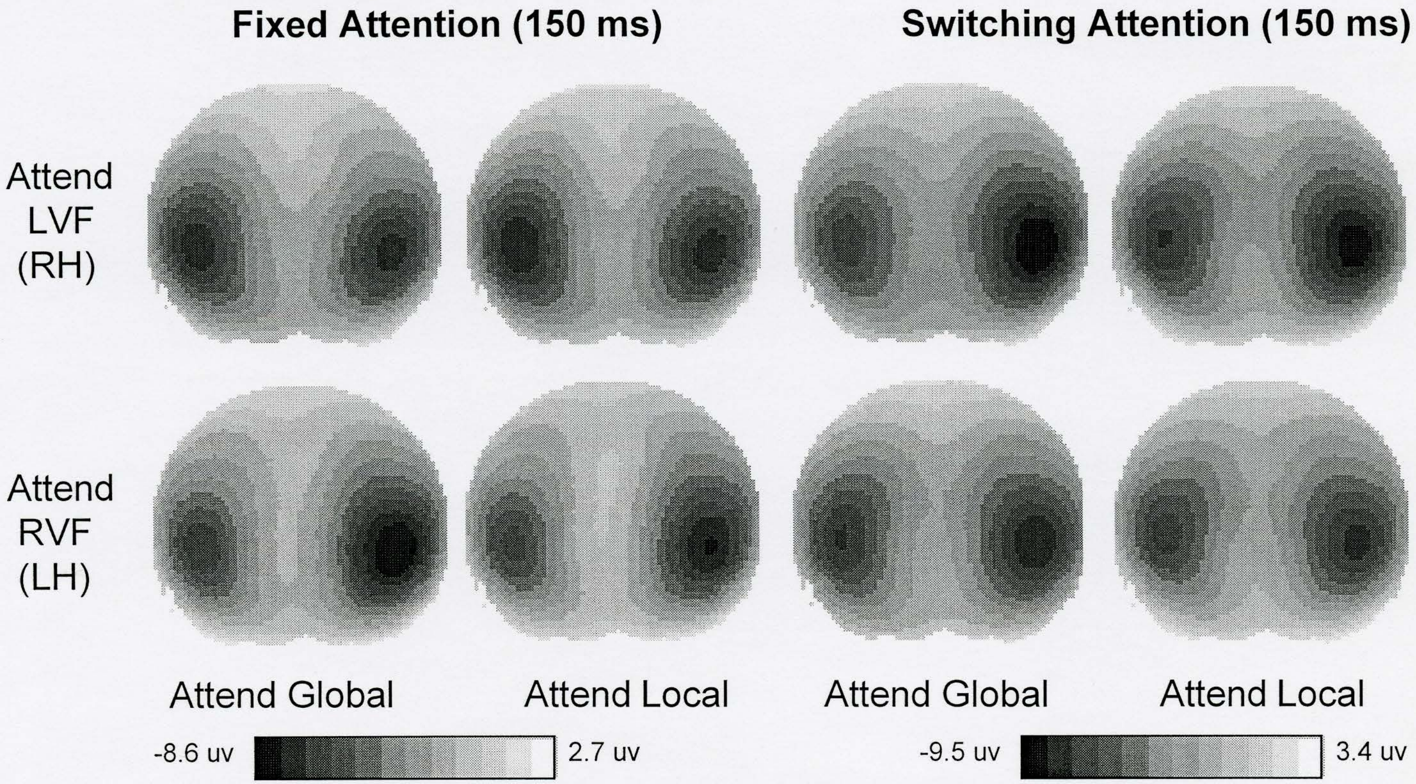


Figure 17b. Posterior topologies representing the spatial distributions of the N1 component in the Fixed versus Switching conditions. Distractors are digits.

N1-Fixed vs. N1-Switching: Digit distractors
Channel X Attention Type: VF

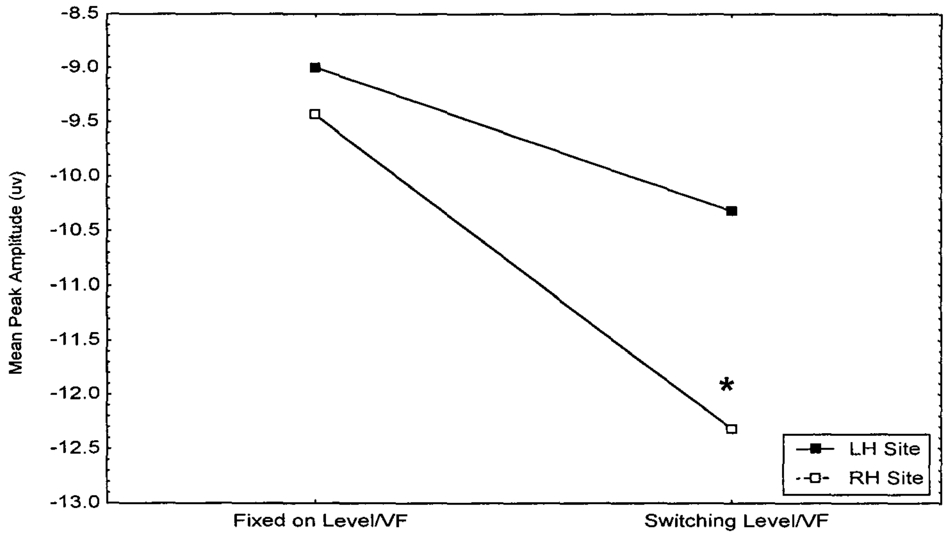


Figure 17c. There were no significant effects of N1 amplitudes within the Fixed and Switching conditions when distractors were digits. However, there was an interaction between N1 amplitudes when N1-Fixed and N1-Switching were compared.

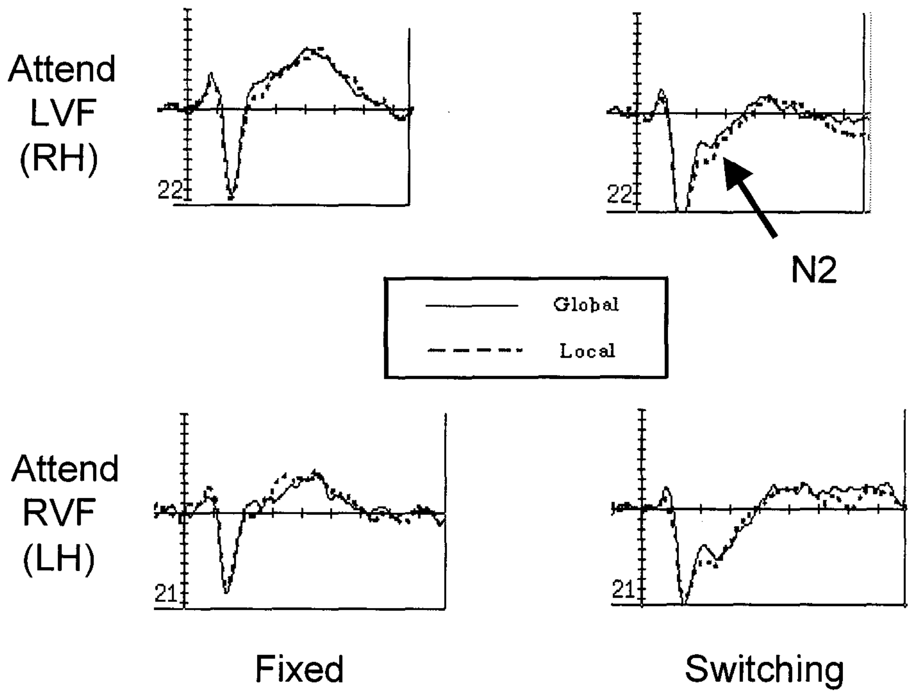


Figure 18a. N2 components arising from fixed and switching attention in the digit distractor condition. Attention to a visual field implies reception of the stimulus in the contralateral hemisphere.

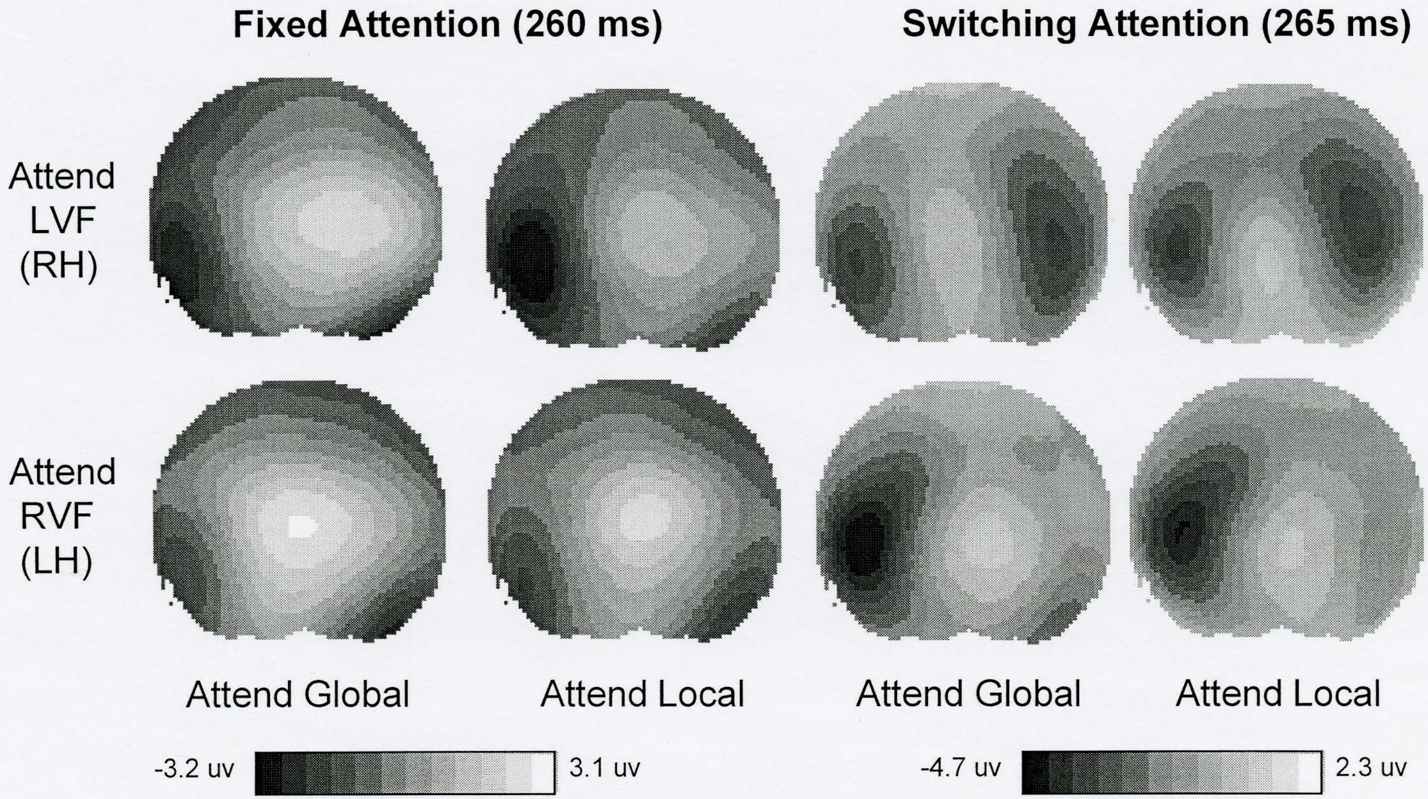
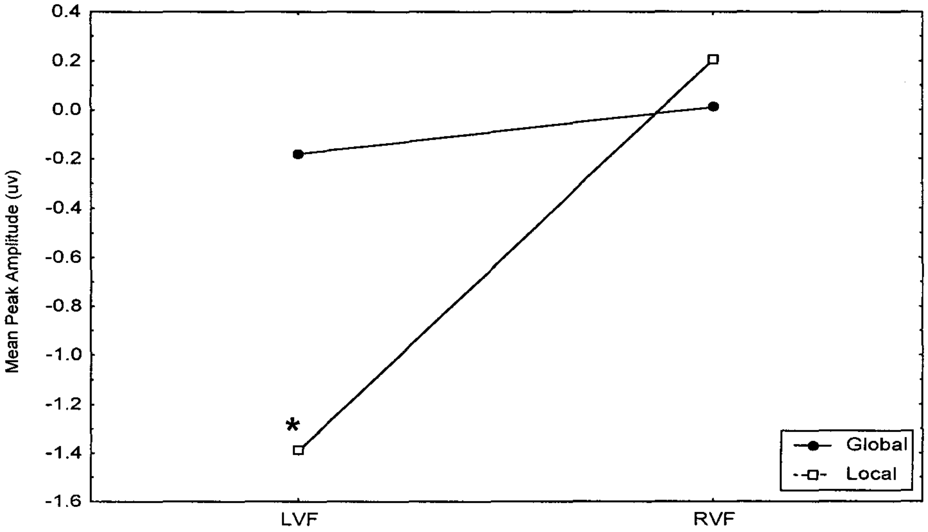


Figure 18b. Posterior topologies representing the spatial distributions of the N2 component in the Fixed versus Switching conditions. Distractors are digits.

N2-Fixed: Digit distractors
Visual Field X Level interaction



N2-Switching: Digit distractors
Channel x Visual Field interaction

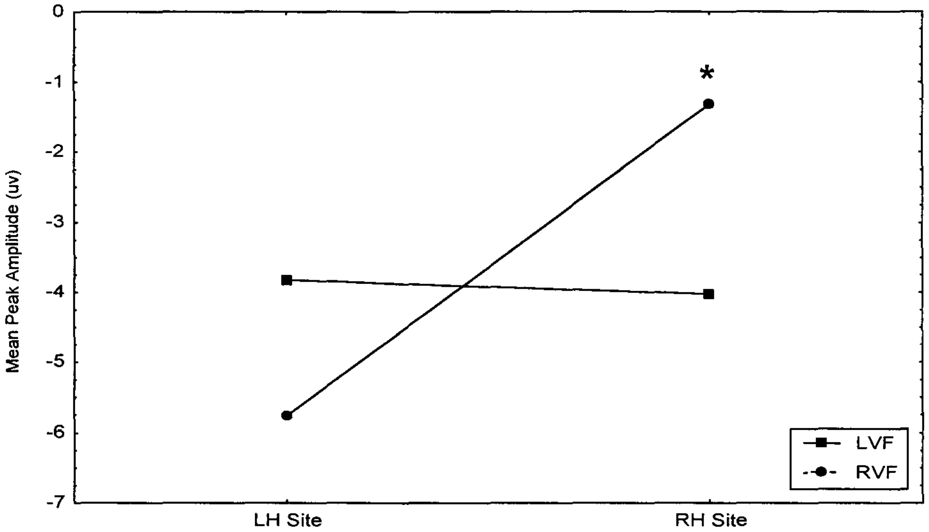
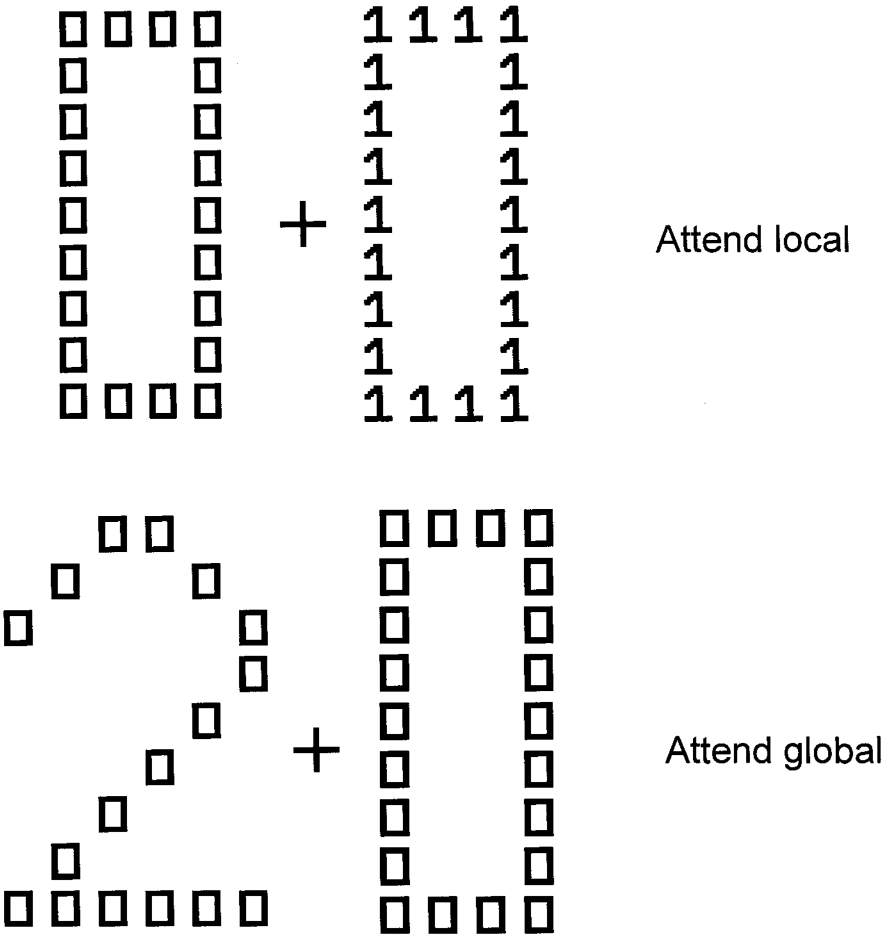


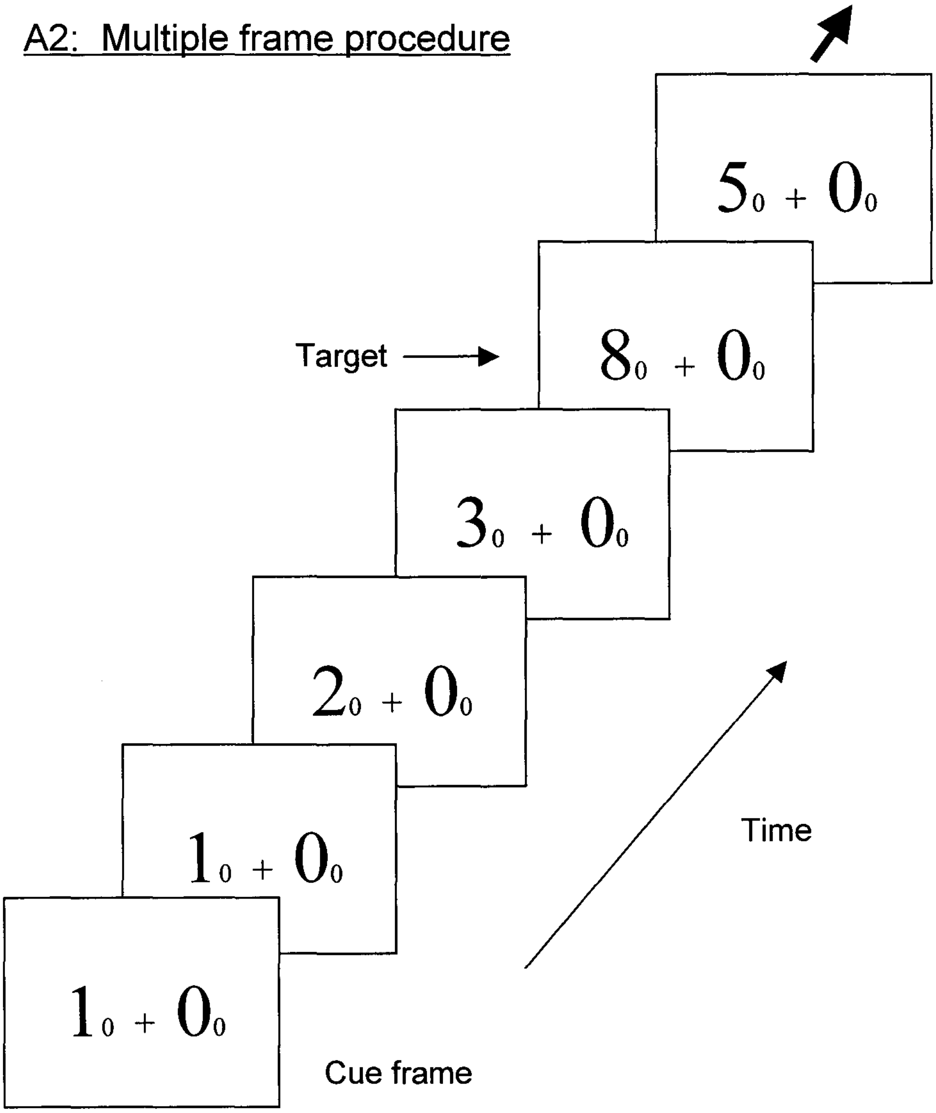
Figure 18c. N2 amplitudes in the Fixed and Switching conditions; distractors are digits.

A1: Stimuli presented in Experiments 1a and 2a



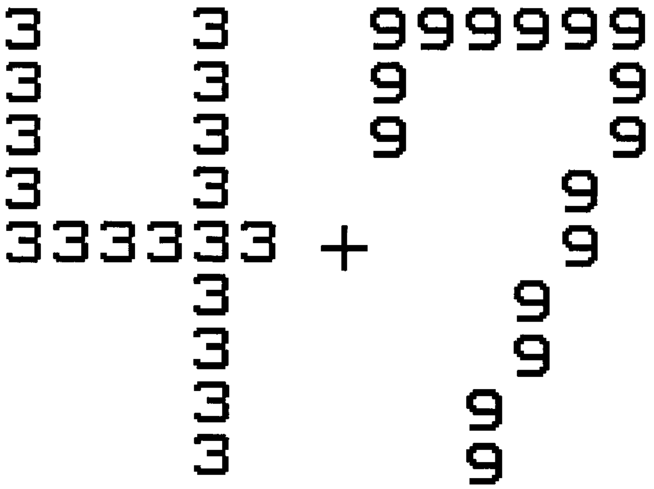
The subject remains fixated on the central cross and attends to the level and visual field indicated for that trial. The unattended level contains box distractors. The top panel illustrates local attention in which local elements are imbedded in a global box. In the lower panel, global attention is illustrated in which the subjects to the global form which is composed of spatially arranged local boxes.

A2: Multiple frame procedure



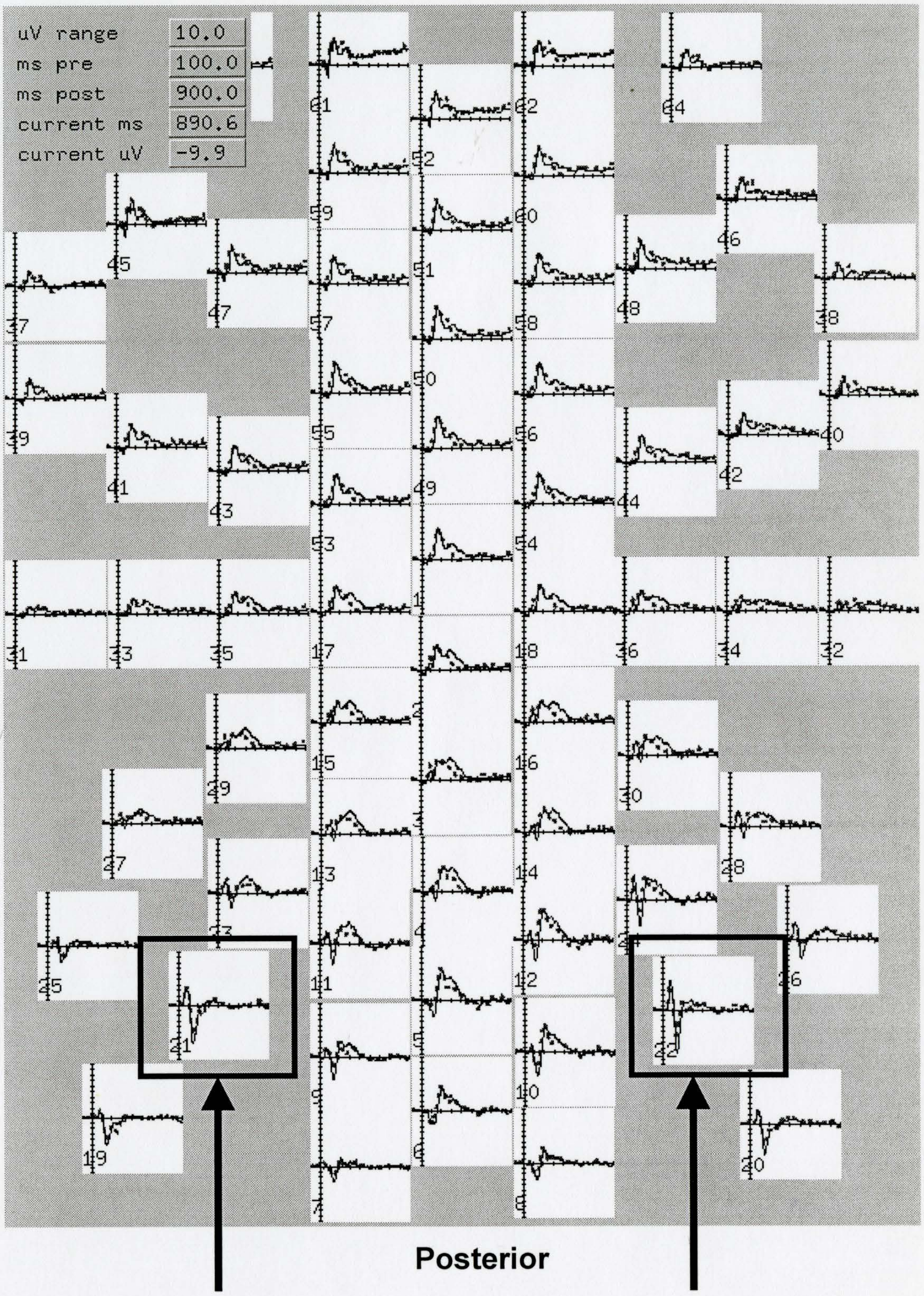
The cue frame, which appears at the beginning of each trial, indicates with the figure ‘1’ the hemifield and level to be attended. Locations to be ignored are indicated with a ‘0’. In this example, the subject must attend to the global level of a figure in the LVF. Then, on a succession of frames, the subject monitors the number sequence as it appears at the specified level and responds to out-of-sequence digits.

A3: Stimuli presented in Experiments 1b and 2b



Subjects were presented with digits at the unattended level in this experiment. Because the digit at the unattended level changed on every frame, this constituted the condition in which variability at the unattended level was present.

A4: Locations of electrodes of interest relative to array



uV range 10.0
ms pre 100.0
ms post 900.0
current ms 890.6
current uV -9.9