PERCEPTUAL LOAD MODULATIONS OF SPATIAL AND NON-SPATIAL VISUAL SELECTION PROCESSES: AN EVENT-RELATED BRAIN POTENTIAL STUDY

by

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A dissertation submitted to the Graduate Faculty in Psychology in partial fulfilment of the requirements for the degree of Doctor of Philosophy, The City University of New York

2006

UMI Number: 3231953

ProQuest Information and Learning Company
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This manuscript has been read and accepted for the
Graduate Faculty in Psychology in satisfaction of the
dissertation requirement for the degree of Doctor of Philosophy.

8/2/06
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Abstract

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by

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The act of paying attention to only a portion of the sensory information that is present is referred to as selective attention. One of the major questions to be answered toward understanding this cognitive mechanism regards the 'locus' of selection- when the selection of this 'relevant' information, and hence the filtering out of irrelevant information, occurs. One theory contends that the locus of selection in vision is determined primarily by the perceptual load (PL) imposed by the relevant stimuli. According to the theory, if this load is relatively high such that attentional capacity is filled, irrelevant stimuli will be filtered early and so will not interfere with task performance. If this load is relatively low, the attentional capacity that remains will be directed automatically to the irrelevant information, even in situations where task interference may result. The current study attempts to test and extend this theory in order to understand better the role of PL. We therefore examined its effects on event-related brain potentials (ERPs)- voltage fluctuations recorded at the scalp that reflect underlying cognitive operations. Participants responded to rare deviant stimuli presented either to a predetermined side of fixation (spatial task) or of a particular color (non-spatial task) while attempting to ignore the other side/color. PL was manipulated by varying the similarity between the deviant and standard stimulus, and was found to modulate the magnitude of the attend – unattend difference waveforms in both the spatial and non-spatial tasks at the predicted latencies. These findings, when considered in light of the fact that no irrelevant information was present when subjects responded to targets as in the interference studies that provide the primary body of support for PL theory, collectively suggest that perceptual load is important not only for preventing attention from being directed to the irrelevant information that is currently present, but also affects attentional selection that is tonically maintained across many experimental trials. The results further suggest that this occurs not only when selection is spatially based as in past studies, but also when it is based upon non-spatial cues. Additions to the existing theory may therefore be warranted.

Acknowledgements

Throughout the time it took to complete this project, I received more encouragement from my family than anyone could ever dream. For this, and for everything they do, I thank them from the bottom of my heart.

There is nothing I can say here that would convey the gratitude and love that I feel for my wife, Doryann. She encouraged me from the first day to the last with astounding patience and trust. Knowing that she was by my side, and always would be, enabled me to get through this difficult process. Thank you, d.

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When we attempt to succeed in a goal-directed task, we usually must attend to those aspects of the environment that are most important at the expense of those that are not. For example, if one wishes to listen to a movie while fellow viewers are talking, attention must be directed toward the voices of the actors and away from the voices of the other moviegoers. This attempt to attend to some sensory stimuli to the exclusion of others is accomplished by a cognitive mechanism commonly called selective attention. Cognitive psychologists have long sought to understand its operation (Driver, 2001). One of the key milestones toward this understanding is determining when the selection of relevant information, and hence the filtering of irrelevant information, occurs. Although selection could potentially occur at any time during information processing between the stimulus event and the response that is made, if any, research studies and the theories that guide them have tended to center around the notion that relevant information is selected either ‘early’ or ‘late’ during the information processing stream.

Early selection is considered to occur when ignored or irrelevant information is filtered at ‘low’ levels of processing, that is, at the point when only rudimentary perceptual information is extracted. In this view, ignored stimuli are not processed past this perceptual level. Late selection occurs when ignored information is filtered later, after it has been fully processed. In this context, ‘fully’ usually refers to the fact that the meaning of the (irrelevant) stimulus has been extracted. Under both views, the ignored stimuli are not willfully, but rather automatically processed by our sensory system.

Proponents of the early selection viewpoint contend that early perceptual processing is serial and, as such, a person's capacity to process even 'low level' perceptual information- basic perceptual qualities such as location or color, is limited (see Broadbent, 1958, 1982; Kahneman & Treisman, 1984; Treisman, 1969 for reviews). These authors claim that in order for the sensory system to process effectively the large amount of perceptual information typically present at a given time, a filter must exist at this early level.

Evidence for early selection has classically come from studies that attempt to determine the degree of processing, or 'fate', of irrelevant stimuli. The earliest of these studies employed a 'shadowing' task in which subjects listened to and repeated (shadowed) a message played to one ear while ignoring another message played simultaneously to the other ear. The typical finding that subjects recall very little to none of the ignored message suggests that the operations performed on these stimuli cease at an early stage of information processing (Cherry, 1953).

This interpretation is supported by the well-established finding that recall is strongly dependent on the level of processing to which stimuli are processed (Craik & Lockhart, 1972; Craik & Tulving, 1975). For example, when items are processed to the semantic level, they will be better remembered than when the same items are processed to only the phonemic level (Craik & Tulving, 1975). Since the level to which an item is processed is directly related to the probability that it is later remembered, poor recall of irrelevant items could very likely be a result of the fact that these items were processed to only a low level.

Although this poor recall for items processed only to a low level can be explained by the operation of an early selective filter, some late selection theorists (e.g., Deutsch &

Deutsch, 1963) counter that the need for attentional selection in forming durable memory traces does not imply that it must also be necessary for identifying stimuli in an ongoing task. In this view then, poor recall of irrelevant items does not suggest the existence of an early filter, but merely highlights the need for attention in the efficient encoding of memories (Johnson & Proctor, 2004). Compounding this issue on both sides is the lack of an objective, reliable method for determining to what degree irrelevant items are actually being ignored since experimenters cannot control attention directly but can only instruct subjects to ignore certain stimuli.

Independent of these issues however is the finding that, in some cases, subjects reported that they were unaware of even substantial changes in the ignored message, such as a change in language (Broadbent, 1958). This provides further support for an early selective filter, since not even basic phonemic information presented to the unattended ear appears to be extracted.

In contrast to the early selection theorists, late selection theorists contend that early perceptual processing takes place in parallel and, due to the unlimited capacity this allows, no filtering is necessary at this stage. In this view, processing does not become serial until later, cognitive stages such as stimulus identification (Norman & Bobrow, 1975). Due to the limitation that serial processing imposes, the flow of information at this stage must be controlled, presumably by attentional/selection processes, such that only relevant information is analyzed.

Support for this view comes from a wide range of studies, including those in which subjects appear to be able to spread their attention across large portions of the visual field (Duncan, 1980; Yantis & Johnston, 1990). In one representative study

(Duncan, 1980), subjects did not have any more difficulty monitoring two locations for the appearance of targets than they did monitoring only one, as measured by their sensitivity of detection (d′). Findings such as these suggest to late selection theorists that perception takes place in parallel across the visual field, and hence there is no need to filter certain stimuli out of the information processing stream.

Further support for the late selection view comes from visual search studies in which subjects search for a target that is located among a set of distractors (e.g., Deutsch & Deutsch, 1963). It is usually found in these studies that when the targets and distractors belong to the same category (e.g., both are letters), reaction time (RT) increases with the number of distractors, but if targets and distractors belong to different categories search time (i.e., RT) does not increase with distractor set size. Rather it remains constant as more and more non-targets (distractors) are added to the search set (called the “pop-out” effect).

These findings are collectively referred to as the category effect (Deutsch, 1977; Jonides & Gleitman, 1976), and can be interpreted as evidence of late selection: if the presence of an increasing number of distractors does not slow search time, then all perceptual information must be processed in parallel. It should be noted, however, that Deutsch (1977) suggested that the category effect could occur because the neural representations of the distractors become activated due to the phenomenon of spreading activation when targets and distractors belong to the same category. The subject must then rely on analysis further along the processing stream in order to reject the distractors, so that more distractors require more analysis and thus search time increases with set size. On the other hand, spreading activation has a much smaller role when targets and distractors are from different categories (the neural representations of the distractors do not become co-activated with the relevants). In this case, the distractors can be rejected at an early level, and so search time does not increase with relevant set size- a finding generally suggestive of early selection.

In addition to the conflicting findings that arise from the various studies cited above, there is also disagreement over the interpretation of the robust finding that response time to a centrally located visual target is slowed when conflicting stimuli are located in the periphery, relative to when the peripheral stimuli do not conflict (Eriksen & Eriksen, 1974). The peripheral stimuli are called ‘flankers’ and this ‘flanker compatibility effect’ (FCE) is cited as evidence of late selection since, if the peripheral stimuli were filtered early (i.e., at the perceptual level), they should not interfere substantially with task performance.

However, Miller (1991) argued that the FCE is not necessarily evidence for late selection, but rather is due to a partial failure of the early selection process that results from the limitation on attentional capacity To test his argument, Miller predicted that it should be possible to find conditions under which early selection will work optimally and thus eliminate the FCE. Assuming that one limitation of early selection is the poor spatial resolution of attentional focus, he designed an experiment in which the distance between the targets and flankers was manipulated. He found that the FCE decreased as the target-flanker distance increased (Miller, 1991). He argued that this finding represented evidence for an early selective filter and that apparent evidence for late selection comes from situations when the early filter simply fails. The same argument can be applied to situations in which search time increases with the size of the stimulus set. It could be that this finding merely represents a failure of the early selective filter, rather than the operation of a 'true' late filter.

In response to this abundance of support for both early and late theories, some researchers have sought to identify aspects of the paradigms used that may be influencing whether the result supports early or late selection. This would then help to delineate the factors that impact when selection takes place rather than taking one viewpoint or the other (Kahneman & Treisman, 1984; Miller, 1991; Yantis & Johnston, 1990).

Treisman (e.g., Kahneman & Treisman, 1984; Treisman, 1969) has been particularly influential, in part by making the distinction between the *filtering* paradigm and the *selective-set* paradigm. In the filtering paradigm, such as the shadowing task of Cherry (1953), there is a large memory load, many responses are possible, and in general the task is relatively complex. In the selective-set paradigm, there is usually only one response to be made, there is a low memory load, and in general the task is quite simple. It is this difference in the complexity of the experimental situation and/or in the task parameters that the authors claim is the most important difference between the two paradigms. Also important is that in the *filtering* paradigm, but not in the *selective-set* paradigm, the property of the stimulus that determines whether it is to-be-attended or ignored (the "stimulus choice") is different from the property that determines the response to be made (the "response choice"). This paradigmatic difference, by itself or in concert with other differences concerning the amount of mental processing necessary to perform the task, may be in large part responsible for the fact that there is abundant support for both late and early selection.

More recently, Nilli Lavie (e.g., Lavie, 1995; Lavie & Cox, 1997; Lavie, Hirst, de Fockert, & Viding, 2004; Lavie & Tsal, 1994) has extended and articulated the approach taken by the earlier researchers, (i.e., to determine the most important factor(s) that determine the locus of selection) with her perceptual load theory. This theory, predicated on the notion that attention is a limited-capacity resource, contends that attention is automatically and involuntarily directed toward available perceptual information until attentional capacity is full. Although an individual may prioritize which information in the visual field will be attended first (e.g., which stimuli, which location, or which stimulus attributes), if this to-be-attended information does not fill attentional capacity, the spare attention will "spill" over to the irrelevant information despite the subject's efforts to ignore it. This irrelevant information is thus processed past the perceptual stage and must then be filtered later so it does not further interfere with the task-at-hand, for example by eliciting an incorrect response.

When instead there is sufficient relevant information available to fill attention, the irrelevant information will not be processed past the early perceptual stages and is therefore said to have been filtered 'early'. Lavie refers to the amount of intentionally attended information at any given time as the 'perceptual load'. Perceptual load theory therefore specifies that irrelevant information will be filtered at the perceptual stage only if perceptual load is relatively high, where perceptual load is defined as the amount of information to which one is attempting to attend at any given moment (where this 'amount' can fluctuate by multiple means). If the perceptual system is not as loaded, the irrelevant information will not be filtered until a later stage and, as such, has the potential to interfere with task performance.

Lavie's perceptual load theory thus integrates the findings of studies that support early selection with those that support late selection in that it specifies the principal task parameter, namely perceptual load, that determines whether early or late selection will predominate. It is important to note that within this framework perception is considered to be automatic not because it does not require attention, but rather because attention is directed involuntarily to available stimuli (Lavie, 1995).

Evidence supporting perceptual load theory is found mainly from studies that employ a variation of the Eriksen and Eriksen (1974) interference paradigm, in which subjects respond to centrally located targets while attempting to ignore peripheral distractors. These studies (e.g., Lavie, 1995; Lavie & Tsal, 1994) sought to determine the locus of selection by inferring the extent to which irrelevant information is processed. They infer this from participants' behavioral performance, usually RT, while perceptual load is manipulated.

In one representative study (Lavie, 1995), participants were instructed to press one button when an "X" appeared in a circumscribed location and another button when "Z" appeared in that location. These stimuli were termed the 'relevant' set because they determined the response the participant should make. The simultaneously presented irrelevant information was either compatible with the relevant set, when both suggested the same response (e.g., the relevant and irrelevant sets are both "X"), incompatible, when they suggested different responses (e.g., the relevant set is an "X" while the irrelevant is a "Z"), or neutral, when they suggested no particular response (e.g., a "P").

Perceptual load was manipulated a number of ways in this study (Lavie, 1995). In Experiment 1, the number of items in the relevant display was increased in the high perceptual load condition relative to the low load condition. In other Experiments in this study (2A, 2B) the processing of feature conjunctions was required in the high perceptual load condition, while only simple features needed to be analyzed in the low load condition. In Experiment 3, subjects performed a go no-go task which required either a simple detection of the target (low load) or identification of the target (high load). These conditions were based on the fact that stimulus detection had been previously shown to be unaffected by set size (Treisman & Gelade, 1980), suggesting that efficient search is taking place. By contrast, stimulus identification is slower with larger set sizes, suggesting that search is relatively inefficient (Grill-Spector & Kanwisher, 2005). Across these multiple experiments, Lavie (1995) consistently found a large amount of RT slowing due to incompatibility in the low load conditions, indicating late selection, while relatively less RT slowing occurred in the high load conditions, indicating early selection.

Therefore, the locus of selection was inferred from the degree to which RT slowed when the irrelevant information was incompatible relative to when it was neutral. The following logic forms the basis of this inference, as well as inferences made by other researchers investigating the locus of selection. On an incompatible trial on which the correct response is given, there is a continuum of possible ‘fates’ of the irrelevant stimulus. On one end of this continuum, the irrelevant information is filtered before perception takes place, and therefore has no effect on a subject’s RT (i.e., subject’s RT is the same on incompatible trials as it is on neutral trials). However, when RT is slowed on incompatible trials, the processing of the irrelevant information must have continued past the perceptual stage, and perhaps as far as the response selection stage (but not response execution stage, since the correct response was made). In this context, perceptual load can be manipulated, and its effect on RT slowing is interpreted as evidence that it affects the locus of selection. It is important to note that when factors related to cognitive control such as working memory are manipulated, the RT effects described above are not obtained (e.g., Lavie et al., 2004) and so the effect of perceptual load on the locus of selection is most likely not an artifact of differences in either the cognitive control required or in overall difficulty between perceptual load conditions.

Lavie and Cox (1997) manipulated perceptual load by varying the similarity between targets and surrounding distractors. In the high load condition, the distractors were similar to the targets in structure (e.g., HMKZXW) whereas in the low load condition they were dissimilar (e.g., OOXOOO). Their manipulation of perceptual load was based upon a part of Treisman's feature integration theory (Treisman & Gelade, 1980), which states that searching for targets is more efficient when targets and distractors are distinguished on the basis of a distinctive feature. Lavie and Cox reasoned that their low load condition would allow for efficient search and so should induce less of a perceptual load than their high load condition, which should lead to relatively inefficient target search. They found that subjects' RTs were slower when the distractor was incompatible (i.e., suggested a different response) with the target and this RT slowing was larger in the low load condition. They interpreted this as evidence in favor of the perceptual load theory since it appeared that distractors were automatically selected when load was low, but not when load was high.

These behavioral studies however are limited by the fact that, although stimulus delivery and other experimental parameters can be precisely controlled and behavioral responses can be reliably measured, the cognitive operations that mediate stimulus and response processing can only be inferred indirectly. Therefore, in studies such as those described above, the effect of perceptual load on the RT compatibility effect could have occurred due to reasons other than an increased amount of attention to irrelevant stimuli under low perceptual load. Brain imaging methods have become available that allow for a more direct study of cognition, which can help to eliminate alternative explanations of the behavioral findings.

Rees, Frith, and Lavie (1997) questioned whether metabolic brain activity in response to irrelevant stimuli was modulated by perceptual load by measuring brain activity in response to irrelevant stimuli under conditions of high and low load. They employed a visual search task wherein subjects searched for target words defined either by font (low load) or by the number of syllables (high load) while irrelevant moving stimuli were simultaneously presented in the periphery. Subjects' brain activity, as measured by positron emission tomography (PET), was measured while they performed the task. PET allows for reasonably spatially precise measurements of brain activity, and the area of the brain that mediates processing of moving stimuli is well-known (Area V5). For these reasons Rees et al. (1997) were able to measure directly the degree to which the irrelevant stimuli were being processed by quantifying the activity of the brain in the region of V5 during presentation of the peripheral moving stimuli even when they were simultaneously presented with the relevant stimuli, which were central and static by contrast.

Rees et al. (1997) found, again in accord with perceptual load theory, that brain area V5 was less active when perceptual load was low relative to when it was high. The same authors later demonstrated that the processing of the irrelevant moving peripheral stimuli was unaffected by perceptual load of the primary task when it was auditory rather than visual, suggesting that loading auditory perceptual processing did not affect the processing of irrelevant visual stimuli (Rees, Frith, & Lavie, 2001). These two studies (i.e., Rees et al., 1997, 2001) collectively represent a dissociation and are therefore strong evidence in favor of the notion that perceptual load *per se* is critical in determining the degree to which irrelevant stimuli are processed.

Yi, Woodman, Widders, Marois, and Chun,(2004) presented faces to subjects under three ‘demand’ conditions that varied in perceptual load, and found similar results. The faces were presented in front of a task-irrelevant background scene. In a low demand baseline condition, subjects performed a one-back task in which they were instructed to press a button whenever the same face was presented on two consecutive trials. In a high demand condition, the faces were visually degraded. In a high working memory load condition subjects performed a two-back task with the intact stimuli. During the presentation of the faces, the authors manipulated how often the same background scenes were repeated. Because neural activity in response to novel stimuli is greater than to repeated stimuli (see Grill-Spector & Malach, 2001), the difference in brain response to a block of trials in which the scenes were frequently repeated was compared to a block in which most of the backgrounds were novel. These differences were interpreted as an index of the degree to which the background scenes were attended, and compared across conditions.

Importantly, they found that this effect was smaller in the high demand condition, indicating that less attention was directed at the irrelevant information under this condition than in the low demand condition, in accord with perceptual load theory. Similar to Lavie (1995), they also found that the high working memory demand condition did not show such an effect, and thus eliminated the possibility that their effects were due to a nonspecific difference in difficulty.

These studies are important because they demonstrate that perceptual load affected directly the brain activity in response to irrelevant stimuli, and from this result they inferred that the irrelevant stimuli were processed to a lesser extent when perceptual load was high. These studies therefore improve significantly upon behavioral studies, which must infer indirectly the relative amounts of attention devoted to the irrelevant stimuli, for example through differences in RT.

Although these brain imaging studies are informative, they do not preclude the possibility that later, post-perceptual processing is suppressed when load is high, and in fact the irrelevant stimuli are processed to the same extent regardless of perceptual load. It is known, for example, that later processing can feed back to modulate activity at earlier stages, in this case from higher brain areas back to striate cortex (Lamme, Super, & Spekreijse, 1998; Murray et al., 2002). As a consequence, the activity observed at a given brain area in PET (or fMRI) studies is a combination of the processing involved in the initial processing, plus any resulting activity due to feedback from higher cortical areas (Rugg, 1998; Spratling & Johnson, 2004). As such, an observed change in this activity could be due to a modulation of the initial processing, to reentrant feedback from top-down cognitive control, or both. It is currently impossible to parse these alternatives since these brain imaging methods can only measure the activity that occurs at a given brain area over several seconds or, at best, hundreds of milliseconds. They therefore cannot resolve feedback processing, which can occur on the order of tens of milliseconds (Rugg, 1998).

By contrast, the event-related potential (ERP) technique can be used to track the cognitive operations active in a given task by plotting the time course of electrical activity while the subject performs the task. Fluctuations in electrical activity of circumscribed areas of the brain appear as peaks and troughs in a graph of voltage as a function of time. Since the operation of the brain is electrical in nature, and is conducted efficiently through the brain and surrounding tissue, it is possible to track these voltage fluctuations on a millisecond time scale, essentially in ‘real time’. Thus, the ERP method may be able to distinguish initial and reentrant feedback processing.

ERPs are recorded at the scalp, and quantify synchronous neuronal activity associated with the presentation of certain stimuli. Continuous electroencephalogram (EEG) is first recorded while the subject performs a task. An averaging process is then performed off-line in which segments of the EEG are averaged together, time-locked to the presentation of whichever types of stimuli the researcher specifies. The background activity of the brain (the ‘noise’) is random with respect to the presentation of the stimuli, and thus averages to near-zero, thereby allowing the brain activity in response to the presentation of the various types of stimuli (the ‘signal’) to be examined. The more individual trials that are collected, the higher the signal-to-noise ratio becomes and the higher the experimenter’s confidence that the voltage deflections observed are in fact time-locked to the presentation of the stimuli and not fluctuations in the electrical field potential due to random ‘noise’.

After the stimulus-locked averaging, comparisons can be made among ERPs in response to the various types of stimuli. This method is particularly well-suited for investigating stimulus processing and its modulation by attention because it allows the researcher to characterize the time course of the processing of attended and unattended stimuli (Hillyard & Anllo-Vento, 1998). In the current study, one such comparison was made between ERPs elicited by relevant stimuli and ERPs elicited by irrelevant stimuli.

The high temporal resolution of this technique has been vital in the study of attention, for example because the upper limit of the timing of differential processing of attended and unattended information can be inferred as the first point at which the ERPs in response to these classes of stimuli begin to diverge significantly (Luck, Woodman, & Vogel, 2000). The major drawback of this technique is that the precise location of the brain activity observed cannot be determined with a high level of confidence. This is due to the fact that electrical activity spreads tangentially in all directions when it reaches the scalp, and so any measurement of this electrical activity could potentially come from any location(s) in the brain.

However, if the pattern of ERP activity across the scalp (i.e., the 'scalp topography') elicited by one type of stimulus differs from the scalp topography elicited by another, the researcher can conclude that the processing of the two types of stimuli was mediated by at least partially non-overlapping brain areas or, conceivably, by activity of the same areas that followed a different time course (McCarthy & Wood, 1985). This difference in topography is identified by a significant Electrode x Condition interaction in an ANOVA (where Condition can be any factor the experimenter wishes to manipulate), provided that appropriate scaling is performed that controls for overall differences in ERP amplitude (Dien & Santuzzi, 2005; Ruchkin, Johnson, & Friedman, 1999). On the other hand, if the pattern of ERP activity does not differ in this way, and there is only a main effect of Condition, it is concluded that the same neural generators mediated processing of both stimulus types, but did so to a different degree. This latter conclusion, however, is tentative since the lack of a significant Electrode x Condition interaction could result from a lack of Power, or simply because the ERP method may not be sensitive enough to detect the activity of active neural generators.

The ERP technique also allows more flexibility in the experimental design than the blood-flow methods because it allows for the rapid and random presentation of different stimulus types, for example relevant and irrelevant stimuli, throughout an experimental block. Rapid, random presentation is currently impossible with blood-flow methods due to the time lag between the activation of a brain area and the flow of blood to that area (as well as the accumulation of a measurable signal). Thus, it is possible with ERPs to eliminate the inherent confounds that may result from presenting each condition in separate experimental blocks (e.g., a difference in overall arousal level across conditions), or by presenting relevant and irrelevant stimuli simultaneously. This latter issue was discussed by Rees et al. (1997, 2001), who acknowledged the possibility that the increased brain activity associated with the processing of the irrelevant moving stimuli under the low load condition in their study may have been caused by the flicker that resulted from the onset and offset of the relevant stimuli, which was more noticeable when participants performed only a visual task (‘low load’) relative to when they performed an additional phonological task (i.e., under high load conditions). Presenting to-be-attended and to-be-ignored stimuli individually eliminates this confound. Although it has recently become possible to conduct event-related fMRI studies that allow this randomized design, the temporal resolution is on the order of hundreds of milliseconds, compared to several millisecond resolution with ERPs, due to the fact that fMRI detects regional cerebral blood flow (rCBF), the signal from which develops relatively slowly as explained above.

ERPs have been used widely in the study of both spatial and non-spatial attention (for review see Luck et al., 2000). In spatial attention tasks, subjects are instructed to attend to a specific area of the visual field. This area is usually specified by a cue, such as an arrow that points to the likely location of an impending stimulus to which the subject has been instructed to make a certain response (for review see Posner & Dehaene, 1994). Comparisons of reaction times, brain responses, or any other dependent variable can then be made between trials in which the stimulus appeared in the cued location and trials in which it appeared in uncued locations.(i.e., between attended and unattended locations, respectively). These ERP studies differ from the behavioral interference studies described earlier in an important way: they require the subject to attend to both the cued and uncued locations, since the critical stimulus can appear in either one.

Non-spatial attention tasks differ from both types of spatial tasks in that the same circumscribed area is always attended, and participants are directed to attend only to those stimuli that possess certain attributes. For example, a participant may be instructed to pay attention to blue letters while ignoring red ones, or to attend only to high-pitch tones and ignore low-pitch tones.

Both spatial and non-spatial selective attention tasks require some amount of initial processing that is the same for both attended and ignored stimuli. In most spatial attention tasks, all stimuli are at a minimum consciously perceived. At a point in time subsequent to this, processing of attended stimuli will begin to differ from that of non-attended stimuli. This differential processing is manifest as changes in the ERP (Näätänen, 1992). Specifically, the first significant difference in the ERP responses between stimuli presented in attended vs. non-attended locations represents the latest time at which selection is taking place (Luck et al., 2000). It is usually found that ERPs elicited by stimuli that appear in attended locations begin to diverge from ERPs to stimuli in non-attended locations at approximately 60 to 100 ms after the stimulus is presented (Luck et al., 2000; Mangun, 1995; Mangun & Hillyard, 1990; Martinez et al., 2001). The relatively early divergence of the ERP due to attention suggests that selection occurs earlier in time when selection is based upon spatial location.

Studies investigating non-spatial attention use a different strategy, both in the task used and in the ERP effects that are investigated. In a typical auditory selection study, subjects are asked to attend to pure tones in one stimulus channel (called the 'relevant' channel) and to ignore tones in the other ('irrelevant') channel. Channels can be distinguished in a number of ways, including the frequency, intensity, and/or duration of the tones. Within each channel, a 'standard' tone is presented with a high probability (e.g., 0.90) and a 'deviant' tone, that varies along a physical dimension, is presented with low probability. The subjects' task is to detect deviant tones in the relevant channel while doing their best to ignore all tones in the irrelevant channel. Näätänen (1992) contends that this task necessarily requires a comparison process between each stimulus and an actively maintained neural representation ('attentional trace') of the relevant standard and, since all stimuli are compared to the attentional trace, both the attended and unattended stimuli require a certain amount of initial processing. This processing is manifest at the scalp as a negative-going deflection in the ERP waveform and so is referred to as the ‘processing negativity’ (PN).

Critically, the PN elicited by irrelevant / unattended stimuli is smaller and/or of shorter duration than the PN elicited by relevant / attended stimuli. This is presumably because the mismatch between the irrelevant stimulus and the attentional trace of the relevant stimuli is detected and processing is stopped or attenuated. When a relevant tone is presented, no such mismatch is detected and so processing continues further for a relevant tone: being relevant, it must be classified as a target or non-target (Näätänen, 1992). The waveform that results from subtracting the ERP elicited by standard tones in the relevant channel from that elicited by the same standard tones when they are in the irrelevant channel is referred to as the ‘negative difference’ (Nd) waveform and reflects additional processing (as reflected in the PN) of relevant stimuli (Näätänen, 1992; Näätänen, Alho, & Schröger, 2001).

ERP studies that employ visual attention tasks in order to investigate selective attention compare a similar attend – unattend ERP difference waveform called the selection negativity (SN). When these tasks are spatial in nature, such as when a cue informs the subject where an impending stimulus is likely to appear, an early ERP component referred to as “N1” is of primary interest. Like Nd, the SN (and enhancement of the N1 component by attention) results when the ERP elicited by irrelevant stimuli is subtracted from the ERP elicited by relevant stimuli and so also presumably reflects the additional processing afforded relevant (attended) stimuli. Importantly, the amplitudes of SN and Nd decrease as the physical similarity between relevant and irrelevant stimuli increases (Harter & Previc, 1978). This suggests that Näätänen’s description of auditory attentional processing (e.g., Näätänen, 1992) is also applicable in the visual domain: in both cases all stimuli elicit a ‘baseline’ amount of processing, manifest as a negative-going voltage deflection that is larger and/or longer in duration in response to relevant stimuli than to irrelevant stimuli.

Perceptual load theory argues that increasing the perceptual load in the relevant channel requires more attention and therefore high load situations leave relatively little attention available for irrelevant stimuli. Following from this framework, and assuming that the magnitude of the SN, and the attentional enhancement of N1, at least partially reflect the relative increase in the processing that a stimulus receives after it has been identified as relevant, perceptual load theory led us to the prediction that the magnitude of the SN would increase with perceptual load since it quantifies the difference between the ERP elicited by relevant and irrelevant stimuli. We reasoned that the difference in attention to relevant and irrelevant stimuli should be greater if the relevant stimuli are occupying all or most attentional resources (under high load), in contrast to when they are not doing so and instead attention gets involuntarily directed to the irrelevant stimuli (under low load). If this is indeed the case, it should be measureable as a decrease in the SN and in the N1 attentional enhancement.

A recent ERP study investigated the role of perceptual load on spatial selective attention (Handy & Mangun, 2000). Using the framework of Mangun and Hillyard (1990), who argued that early perceptual selection is more likely to be engaged when target detection is relatively difficult, the authors defined perceptual load as the degree to which a given task demands attentional resources at early perceptual stages of stimulus processing and operationalized this definition by manipulating the difficulty in identifying the targets (see Duncan & Humphreys, 1989) in a forced two-choice visual probabilistic cuing paradigm. They presented dissimilar, and therefore easily discernable, targets in the low perceptual load condition and in the high perceptual load condition presented targets that were more similar and therefore difficult to discern.

Handy and Mangun (2000) applied the logic that, if targets were perceptually similar to non-targets, discriminating them would require higher-grained perception than if targets and non-targets were more different from each other. The N1 component of the ERP in response to the stimuli presented in cued (attended) and uncued (unattended) locations were compared in an attempt to determine whether perceptual load affected early spatial selection.

Although the results of the three experiments that comprised this study were somewhat variable, notably with regard to whether the attention effect was affected by perceptual load at the P1 or the N1 component, the authors contended that their ERP results supported directly the notion that perceptual load can affect spatial selection at the early stages of processing. Notably, they found that the N1 enhancement that occurred when stimuli appeared at cued locations, compared to when they occurred at uncued locations, was greater when perceptual load was high relative to when it was low.

The Handy and Mangun (2000) study is especially important to the current study because the authors were able to quantify the effect of perceptual load on a physiological measure of early processing rather than inferring from behavioral data alone perceptual load's influence on attentional processing. This study therefore made us more confident in the viability of perceptual load theory as well in the ability of the ERP method to detect perceptual load effects on ERP correlates of selective attention. However, since a spatial cuing paradigm was used, the electrophysiological correlates of non-spatial selection were not addressed.

Providing strong support for the assertion that the magnitude of the N1 component reflects the amount of attentional resources directed toward a given type of stimulus, Mangun and Hillyard (1990) instructed subjects to attend covertly to either the left or right of fixation and to detect infrequent targets on the attended side (four letter arrays that contained the letter ‘T’) that were presented among frequent standards (four-letter arrays without a “T”). They found that a negative-going ERP component (N1 / N180) was larger in response to standard stimuli that appeared on the attended side relative to the same stimuli when it appeared on the unattended side. In addition to this selective attention task, subjects performed a divided attention task in which they were instructed to respond to targets on both the left and the right sides. The authors assumed that subjects would direct the most attention to relevant standard stimuli, the least amount to irrelevant standard stimuli (both in the selective attention task), and an intermediate amount in the divided attention task. The magnitude of the N1 in this task was larger than it was in response to irrelevant standards but smaller than it was in response to relevant standards in the selective attention task described above. These findings provide strong evidence that the magnitude of the N1 component reflects the amount of attention directed at a given type of stimulus.

Although a few ERP studies have been conducted that examine the role of perceptual load on visual spatial attention (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001), there is a surprising lack of ERP studies that examine the role of perceptual load on non-spatial attentional processing. This is important because spatial and non-spatial attention appear to be mediated by different (though probably overlapping) brain areas (Rugg, Milner, Lines, & Phalp, 1987).

Despite the obvious differences between spatial and non-spatial attention, in both cases there are differences evident in the ERPs elicit by attended and unattended items, although they are likely to begin somewhat later in time in non-spatial tasks (Hillyard & Anllo-Vento, 1998). For example, Anllo-Vento, Luck, and Hillyard (1998) found that subjects' ERPs exhibited a deflection that was more negative to attended colors than it was to unattended colors. This difference, that is, the SN subtraction waveform, peaked at approximately 250 ms post-stimulus, and was maximal at posterior electrodes. This is in contrast to earlier attentional modulation of ERPs that is usually observed in spatial attention tasks such as cuing paradigms (Handy & Mangun, 2000), detectable as an enhancement of the P1/N1 components. However, it should be noted that the timing of the attentional modulations on the ERP can vary substantially, depending on various task parameters.

In a previous study in our laboratory, we examined the effects of perceptual load on the magnitude of the Nd in an auditory selective attention task (Barnhardt, Duff, Barrett, Ritter, & Gomes, submitted). Perceptual load was manipulated across three levels by varying the number of non-target deviants in the relevant channel (High- 3, Medium- 1, and Low- 0). This operational definition was in accord with one of the definitions offered by Lavie (2005), namely that perceptual load can be defined as the number of different-identity stimuli present in the relevant set. We predicted that Nd magnitude would decrease with perceptual load since low load conditions would lead to the irrelevant stimuli being automatically selected, while high load conditions would fill attention and so would not foster this 'spillover' effect. If accurate, this would result in similar ERP responses to relevant and irrelevant tones, whereas the opposite would occur under high perceptual load. We found that RT increased with perceptual load, suggesting our manipulation of load was successful, but found no differences in the Nd across load conditions. We concluded from these findings that the effects of perceptual load on RT were not a result of increased attention to the unattended tones. Thus, we did not find support for perceptual load theory in that study.

There are, however, a number of possible explanations for our lack of ERP findings in that study unrelated to the efficacy of perceptual load theory or our general approach in applying it. Most important to the current study, it is possible that the operational definition offered by Lavie (2005) is simply not applicable to the auditory modality. Specifically, it could be the case that increasing the number of relevant items only loads perceptual routines if they are presented simultaneously. To eliminate this possibility in the current study, we used the other principal operational definition offered by Lavie, namely that perceptual load increases when, "…for the same number of items perceptual identification is more demanding on attention." (Lavie, 2005, p.283). It also remains an empirical question whether the theory would be supported in an analogous two-channel selective attention paradigm in the visual modality.

In the current study we employed a spatial-based, two-channel visual selective attention paradigm as a means to this question, and to test generally whether perceptual load theories such as Lavie's accurately describe the operation of selective attention in the visual modality. We tested the theory further by employing an analogous non-spatial task wherein the stimulus channels were defined by color. It is known that attentional ERP effects tend to occur later in time when attention is based on non-spatial cues relative to when it is based on spatial cues. This is likely because a ‘gain’ mechanism, which biases any inputs at the attended location(s), appears to play a primary role in spatial tasks (Hillyard & Anllo-Vento, 1998; Hillyard, Vogel, & Luck, 1998), but would not necessarily benefit performance in a non-spatial task. Since attentional enhancement of early ERP components such as the N1 are possible but unreliable in non-spatial tasks (Hillyard & Anllo-Vento, 1998; Vogel & Luck, 2000), we expected this enhancement and thus predicted its modulation by perceptual load only in the spatial task.

In accord with the previous findings discussed above, we expected a SN in the non-spatial task and, again based upon the perceptual load framework, we predicted that the magnitude of the SN would increase with perceptual load.

Perceptual load was therefore manipulated in spatial and non-spatial selective attention tasks. In both tasks we operationally defined perceptual load as the difficulty in discriminating targets from non-targets, as did Handy and Mangun (2000) (discussed above). Although a convention regarding how perceptual load should be operationalized has not yet emerged from the literature, and is essentially a vague concept, our manipulation was likely to load perceptual routines rather than cognitive control operations such as working memory (Handy & Mangun, 2000; Lavie, 1995).

We manipulated load across two levels, where the standard and deviant stimuli were more similar in the high load condition than they were in the low load condition. In contrast to Handy and Mangun (2000), who used a forced-choice cuing task that required responses to all stimuli, we employed a two-channel selective attention task wherein participants were instructed to attend to only one ‘channel’ and to ignore the other. Channel was defined either by color (non-spatial task) or by location (spatial task). In both tasks, subjects were given the same instructions- to attend to one channel (the ‘relevant’ channel) and to respond to infrequent deviant stimuli within it, while ignoring the other, ‘irrelevant’ channel. The standard stimulus was a symbol determined to be unfamiliar to subjects (see Appendix D). In the non-spatial task, all stimuli were presented at fixation and subjects were instructed to attend only to symbols appearing in a certain color. In the spatial task, all stimuli were black and subjects were instructed to attend only to symbols that appeared in a certain location

There are advantages of the current approach over behavioral or brain imaging methods. First, there is evidence that the SN, and attentional modulation of the N1, are elicited reliably in attention tasks (Frith & Friston, 1996; Handy & Mangun, 2000). Specifically, these ERP changes are believed to reflect the differential processing devoted to attended and unattended stimuli and therefore provide a means to examine directly the modulation of attention rather than inferring it from behavioral data such as reaction time. Second, it is advantageous to present relevant and irrelevant stimuli at different times because of the ambiguity in interpreting the brain activity that may result by presenting them simultaneously in this type of paradigm (see above and (Rees et al., 1997, 2001)). ERPs are well-suited for this paradigm since they allow for the randomization of trials, in this case the random presentation of attended and unattended trials as well as deviants and target deviants, within a single experimental block.

We predicted an enhancement of the N1 component elicited by attended relative to unattended visual stimuli in the spatial task and further predicted that this enhancement would increase when perceptual load was increased. We analogously predicted that the magnitude of the difference between the ERPs elicited by relevant and irrelevant visual stimuli, reflected in the SN waveform, would increase with perceptual load in the non-spatial task. We compared ERP difference waveforms across load conditions instead of comparing the original waveforms because EEG activity can vary depending on overall arousal level concomitant with task demands (Coull, 1998) or other nonspecific factors that are not pertinent to the current study and, since task demands varied across load conditions, differences in arousal would be expected and could in turn contribute to any observed difference in the ERPs elicited in the two conditions. By subtracting the original waveforms prior to the comparisons across load conditions, these differences in overall arousal across tasks are eliminated.

In both tasks, we expected the attend – unattend difference to be maximal at posterior electrode sites and we sought to detect this difference as a significant Stimulus Relevance (relevant, irrelevant) x Perceptual Load (high, low) interaction in a repeated-measures ANOVA, performed on amplitude data extracted from an array of posterior electrodes.

The latency of the SN peak is difficult to predict because it is potentially affected by many task parameters, including the complexity of the stimuli and the feature that determines whether or not the stimuli are to-be-attended (e.g., location vs. color as in the current study). We therefore determined the epoch to be examined by locating the peak latency of the grand average attend - unattend subtraction waveform (i.e., the point in time at which the subtraction waveform reaches its maximum amplitude), +/- 25 ms. We determined the epoch to be analyzed in the spatial task by finding the peak latency of the N1 component, reliably elicited in spatial selective attention tasks (Correa, Lupianez, Madrid, & Tudela, 2006; Hink, Van Voorhis, Hillyard, & Smith, 1977), +/- 25 ms.

Significant effects of perceptual load on the attentional ERP modulations would add to the current literature on perceptual load theory by providing direct electrophysiological support either for or against it as it pertains to both spatial and non-spatial visual selection. The critical comparison across tasks was the degree to which Perceptual Load affected the magnitude of the Stimulus Relevance effect, as measured by the amplitude of the SN difference waveform (i.e., the Task x Perceptual Load x Stimulus Relevance interaction in the ANOVA). The Task (Spatial vs. Non-spatial) x Stimulus Relevance (relevant, irrelevant) x Perceptual Load (high, low) interaction addressed the extent to which the perceptual load effects on the differential processing of relevant and irrelevant stimuli differ when those stimuli are distinguished by a non-spatial attribute (color) relative to when they are distinguished by a spatial attribute (location).

Methods

Participants

Eighteen subjects were recruited either from the City College of New York campus and paid US$10/hr or they were recruited through an introductory psychology course and given course credit for their participation. All participants gave informed consent, demonstrated at least 20/20 vision, and reported normal color vision. Two of the subjects requested to end the protocol early due to time constraints, and so were dropped from the analysis. All of the remaining sixteen subjects (9 female) reported being right-handed and scored an average of 44.8 on the short version of the Edinburgh Handedness Inventory (Oldfield, 1971) (see Appendix A.). The mean age of participants was 22.3 years (SD = 7.3, range 18 - 42).

Stimuli

In the non-spatial selective attention task, stimuli consisted of a novel two-stemmed symbol, presented in blue and in red (see Appendixes D-G). The standard symbol (probability 0.80) was presented centrally at a fixation cross at the center of the computer screen and subtended 0.88 degrees (horizontal) x 0.90 degrees (vertical) of visual angle. The fixation spot was removed from the screen when stimuli were presented. Stimulus onset asynchrony (SOA) varied randomly between 900 and 1350 ms, in 5 ms steps with a rectangular distribution. Stimulus duration was 500 ms, but could be terminated by a response. Deviant stimuli (probability 0.20) were identical to standard stimuli, except that one of the stems was displaced either 0.075 or 0.180 degrees of visual angle. One of four possible rotations of the stimuli (0, 90, 180, or 270 degree rotation) was used for each subject.

In the spatial selective attention task, the same two-stemmed symbol that was used in the non-spatial task was presented in black, either to the left or to the right of fixation. When presented on the left, the rightmost border of the symbol was at fixation, and extended 0.88 degrees horizontally to the left (0.90 degrees vertical). When presented on the right, the leftmost border of the symbol was at fixation, and extended 0.88 degrees horizontally to the right (0.90 degrees vertical). SOA, standard and deviant probability, and the displacement of the stem in the deviant stimuli were the same as in the non-spatial task. Likewise, the same four rotations of the stimuli were used for each subject.

General Procedure

Subjects sat in a cushioned chair in a dimly lighted, sound-attenuated chamber. The chair was adjusted such that the subject's eyes were 1 m from the center of the computer screen that delivered the stimuli. Subjects took one scheduled break as well as any other short breaks that they requested, at which time(s) they were permitted to leave the chamber. The experiment, including completion of forms, placement and removal of the electrode cap, and debriefing, lasted approximately three hours. Cap placement took approximately 20 minutes. While instructions were read to subjects, a graphical representation of the task was displayed on the computer screen (see Appendixes D-G). At the conclusion of the study, subjects were sent a printout of their individual ERPs along with grand average ERPs.

Experimental Design and Procedure

A repeated-measures design was used with factors Task (non-spatial, spatial), Perceptual Load (high, low), and Stimulus Relevance (relevant, irrelevant). Stimulus Type (standard, deviant) was also manipulated, but only ERP responses to standard stimuli were of interest in the current study. ERP data were examined at an array of posterior sites (TP7/8, P7/8, P5/6, PO7/8, and O1/2) and at a corresponding array of anterior sites (FP1/2, AF7/8, F5/6, F7/8, and FT7/8). Thus, Scalp Region (Posterior, Anterior) was also used as an independent variable.

In the non-spatial selective attention task, participants were instructed to attend to symbols presented in either red or blue, and to ignore symbols presented in the other color. These were referred to as the ‘relevant channel’ and ‘irrelevant channel’, respectively. Participants were further instructed to respond to infrequent deviant stimuli in the relevant channel, which were presented among frequent standard stimuli. We refer to this as the non-spatial task because all stimuli were presented in the same location, and Stimulus Relevance was determined by a non-spatial attribute (color).

In the spatial selective attention task, participants were instructed to attend to symbols presented either to the left or right of fixation, and to ignore symbols presented to the other side. As in the non-spatial task, these were referred to as the ‘relevant channel’ and ‘irrelevant channel’, respectively. Participants were further instructed to respond to infrequent deviant stimuli in the relevant channel, which were presented among frequent standard stimuli. We refer to this as the spatial task because stimuli were presented in different locations, and Stimulus Relevance was determined by a spatial attribute (location). Thus, the two tasks were identical with the exception of 1) the color and location of the stimuli- either red and blue, presented at fixation (non-spatial task) or black, presented to the left and right of fixation (spatial task) and 2) the stimulus attribute that determined relevance- color (non-spatial task) or location (spatial task).

Prior to performing the tasks, subjects were shown examples of standard and deviant stimuli, and were also shown a schematic representation of the task (see Appendixes B & C for complete instructions). In the low perceptual load conditions, one stem of the target symbol was displaced 0.180 degrees relative to the standard symbol, while in the high perceptual load conditions it was displaced 0.075 degrees. Thus, the similarity between the standard and deviant stimuli, and hence the difficulty in discriminating targets, was manipulated across these conditions. Each condition was presented in four separate blocks. In the non-spatial task there were two blocks in which red was the relevant color and two in which blue was the relevant color, while in the spatial task there were two blocks in which left was the relevant side and two in which right was the relevant side. Each block comprised 320 trials and lasted about six minutes. The probability of standards was 0.40 in each channel (i.e., target probability was 0.10 overall). Trials were presented quasi-randomly, with the constraint that the first deviant was not displayed until the corresponding standard had been presented at least three times. Each condition comprised a block in which subjects attended to the left (or red), then attended to the right (or blue). After all conditions were completed, the subject repeated the sequence, for a total of four blocks per condition. The order of conditions was counterbalanced across subjects (see Table 2).

EEG recording and data analysis

Electroencephalographic (EEG) activity was recorded from 64 scalp sites using sintered Ag-AgCl active electrodes, (integrated with the first amplification stage) that were connected to an elastic cap, with nose reference. The electrode sites, embedded in the cap, were located according to the American Electroencephalographic Society Guidelines (1991): FP1, AF7, AF3, F1, F3, F5, F7, FT7, FC5, FC3, FC1, C1, C3, C5, T7, TP7, CP5, CP3, CP1, P1, P3, P5, P7, P9, PO7, PO3, O1, Iz, Oz, POz, Pz, CPz, FPz, Fp2, AF8, AF4, AFz, Fz, F2, F4, F6, F8, FT8, FC6, FC4, FC2, FCz, Cz, C2, C4, C6, T8, TP8, CP6, CP4, CP2, P2, P4, P6, P8, P10, PO8, PO4, and O2 (see Table 1 and Figure 1). Electrodes were also placed on the left and right mastoids. EEG was collected with a band pass of 0.5 - 30 Hz (6 dB/octave) and digitized at 512 Hz. Eye movements were recorded from 4 additional electrodes, placed above and below the left eye and 2 cm from the outer canthi of each eye. Trials containing signals from any electrode that exceeded +/- 100 µV during any sampling point in the epoch were considered to be artifactual (e.g., to contain electrooculogram (EOG)) and were excluded prior to averaging.

Figure 1. 64 channel electrode montage.

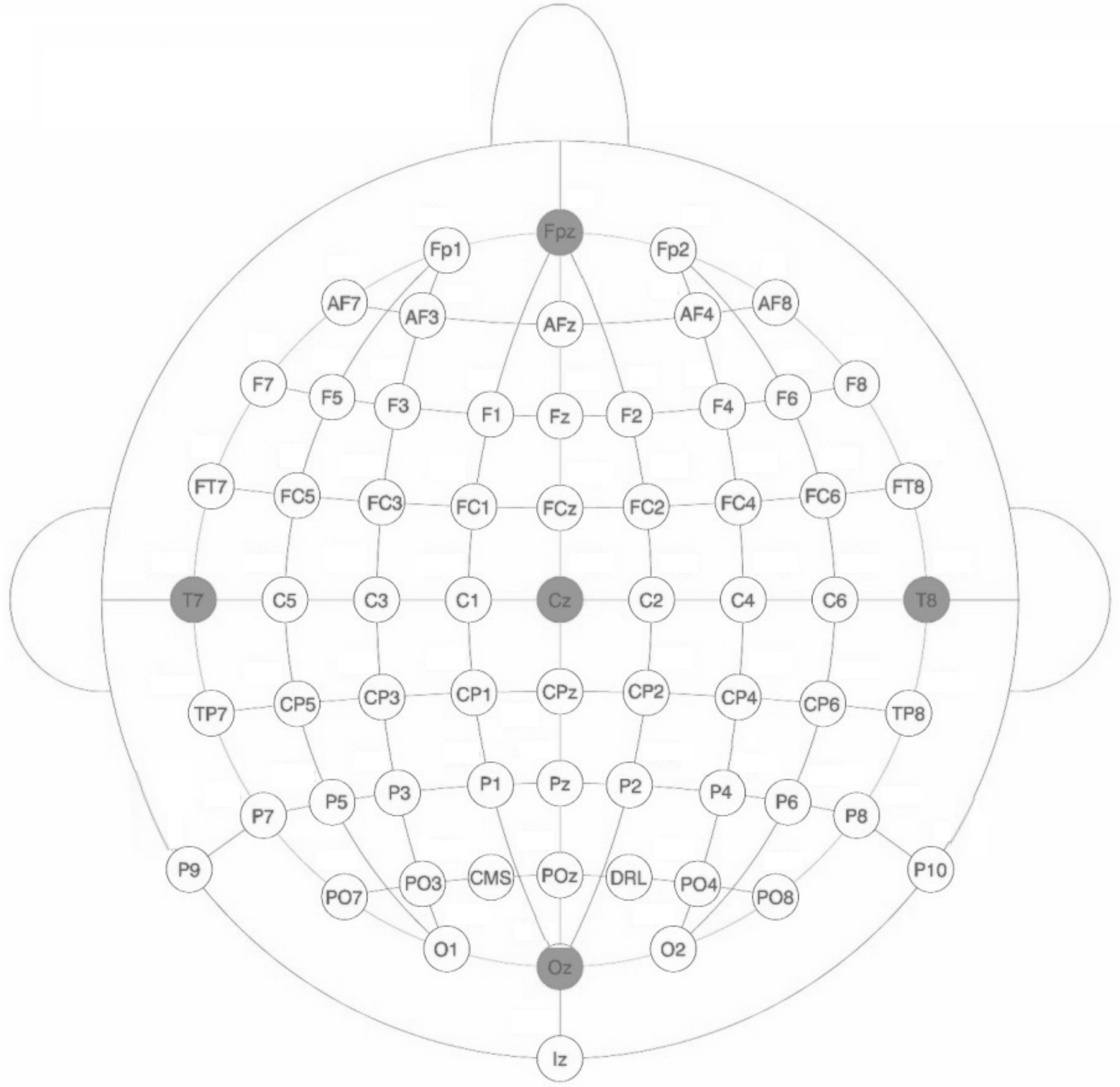


Table **1**. Spherical coordinates in degrees, by azimuth (Az.) from Cz (positive values are right hemisphere, negative are left hemisphere) and latitude (Lat.), from T7 (for left hemisphere, and from T8 for right hemisphere, positive values are counterclockwise, negative are clockwise).

	Az.	Lat.		Az.	Lat.		Az.	Lat.		Az.	Lat.
Fp1	-92	-72	CP5	-72	21	Fpz	92	90	C2	23	0
AF7	-92	-54	CP3	-50	28	Fp2	92	72	C4	46	0
AF3	-74	-65	CP1	-32	45	AF8	92	54	C6	69	0
F1	-50	-68	P1	-50	68	AF4	74	65	T8	92	0
F3	-60	-51	P3	-60	51	AFz	69	90	TP8	92	-18
F5	-75	-41	P5	-75	41	Fz	46	90	CP6	72	-21
F7	-92	-36	P7	-92	36	F2	50	68	CP4	50	-28
FT7	-92	-18	P9	-115	40	F4	60	51	CP2	32	-45
FC5	-72	-21	PO7	-92	54	F6	75	41	P2	50	-68
FC3	-50	-28	PO3	-74	65	F8	92	36	P4	60	-51
FC1	-32	-45	O1	-92	72	FT8	92	18	P6	75	-41
C1	-23	0	Iz	115	-90	FC6	72	21	P8	92	-36
C3	-46	0	Oz	92	-90	FC4	50	28	P10	115	-40
C5	-69	0	POz	69	-90	FC2	32	45	PO8	92	-54
T7	-92	0	Pz	46	-90	FCz	23	90	PO4	74	-65
TP7	-92	18	CPz	23	-90	Cz	0	0	O2	92	-72

The continuous EEG was epoched from 100 ms before to 500 ms after stimulus presentation. Trials of each type were averaged together, time-locked to the presentation of the stimulus, to form the ERP waveforms in each experimental condition (see below). Each of the waveforms displayed were averaged from approximately 275 trials for each of the sixteen subjects (i.e., approx. 4,400 total trials contributed to each waveform).

Base-to-peak area data were calculated from subjects’ ERP averages in response to relevant and irrelevant standard stimuli. These data were extracted from electrodes TP7, TP8, P5, P6, P7, P8, PO7, PO8, O1, and O2 for analysis of posterior scalp, and from FT7, FT8, F5, F6, F7, F8, AF7, AF8, FP1, and FP2 for analysis of anterior scalp, at both the 175 - 225 ms and 275 - 325 ms post-stimulus time windows. The posterior electrode sites were chosen based on past selective attention studies (e.g., Anllo-Vento et al., 1998), and because the theory being tested predicts that load will mediate the activity of visual cortical areas that mediate visual perception (Handy et al., 2001). The anterior sites are a spatially analogous array from anterior scalp.

A repeated-measures, Greenhouse–Geisser corrected factorial ANOVA was used to analyze the electrophysiological data. The 175 - 225 ms time window was chosen based on the latency of the first negative peak observed in the grand average ERPs (i.e., the N1 component), +/- 25 ms. The 275 - 325 ms time window was chosen based on peak amplitude latency of the relevant minus irrelevant subtraction waveform (i.e., the SN), +/- 25 ms. The main comparison of interest- the difference in SN magnitude /attentional enhancement elicited across the perceptual load conditions- was made by examining the interaction between Perceptual Load (low, high) and Stimulus Relevance (relevant, irrelevant) in each task. This interaction was also examined across Task (non-spatial, spatial) and Scalp Region (anterior, posterior), along with other effects of interest.

A response that was made between 200 and 1200 ms after the presentation of a target was considered a Hit and the reaction time (RT) was recorded. False Alarms (FAs) to relevant standards, irrelevant standards, and irrelevant deviants were also recorded. Corresponding repeated-measures ANOVAS were performed on reaction time and accuracy data, without the Stimulus Relevance factor (since subjects were instructed to respond only to relevant deviants).

Table **2**. Presentation of conditions for each subject. NS = Non-spatial task, S = Spatial task, LPL = Low Perceptual Load, HPL = High Perceptual Load.

Subject	Order of presentation							
# 1	NS,HPL	NS,LPL	S,HPL	S,LPL	NS,HPL	NS,LPL	S,HPL	S,LPL
# 2	S,HPL	NS,HPL	NS,LPL	S,LPL	S,HPL	NS, HPL	NS,LPL	S,LPL
# 3	S,LPL	NS,HPL	S,HPL	NS,LPL	S,LPL	NS,HPL	S,HPL	NS,LPL
# 4	NS,LPL	NS,HPL	S,LPL	S,HPL	NS,LPL	NS,HPL	S,LPL	S,HPL
# 5	NS,LPL	S,HPL	S,LPL	NS,HPL	NS,LPL	S,HPL	S,LPL	NS,HPL
# 6	NS,HPL	S,HPL	S,LPL	NS,LPL	NS,HPL	S,HPL	S,LPL	NS,LPL
# 7	S,LPL	NS,HPL	NS,LPL	S,HPL	S,LPL	NS,HPL	NS,LPL	S,HPL
# 8	NS,LPL	NS,HPL	S,HPL	S,LPL	NS,LPL	NS,HPL	S,HPL	S,LPL
# 9	NS,HPL	S,HPL	NS,LPL	S,LPL	NS,HPL	S,HPL	NS,LPL	S,LPL
# 10	S,LPL	NS,LPL	S,HPL	NS,HPL	S,LPL	NS,LPL	S,HPL	NS,HPL
# 11	S,HPL	S,LPL	NS,HPL	NS,LPL	S,HPL	S,LPL	NS,HPL	NS,LPL
# 12	NS,LPL	S,LPL	NS,HPL	S,HPL	NS,LPL	S,LPL	NS,HPL	S,HPL
# 13	S,LPL	S,HPL	NS,LPL	NS,HPL	S,LPL	S,HPL	NS,LPL	NS,HPL
# 14	S,HPL	NS,LPL	NS,HPL	S,LPL	S,HPL	NS,LPL	NS,HPL	S,LPL
# 15	NS,LPL	S,HPL	NS,HPL	S,LPL	NS,LPL	S,HPL	NS,HPL	S,LPL
# 16	NS,HPL	NS,LPL	S,LPL	S,HPL	NS,HPL	NS,LPL	S,LPL	S,HPL

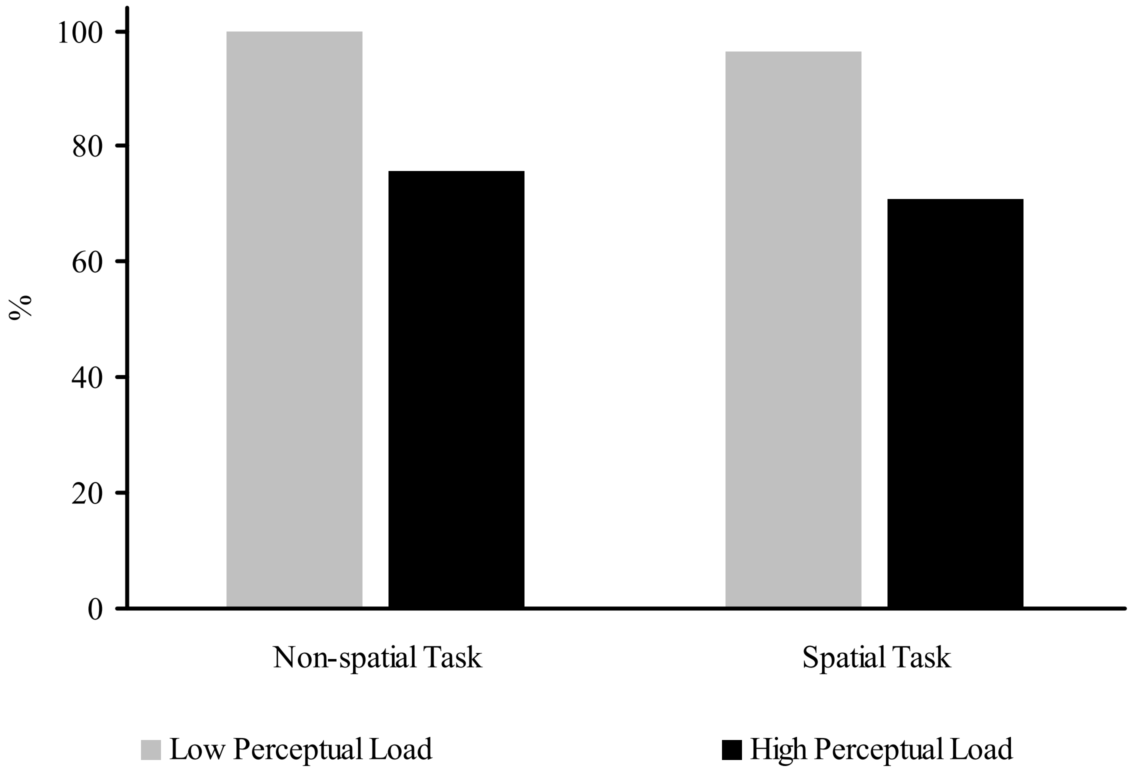
Results

1. Behavioral Performance

1.1. Accuracy

Subjects' Hit rates in the non-spatial task (87.7 %) did not differ significantly from their Hit rates in the spatial task (83.6 %) [$F(1,15) = 2.57$, $p = 0.13$, $\eta_p^2 = 0.15$], but were higher when perceptual load was low (98.1 %) relative to when it was high (73.3 %) [$F(1,15) = 49.65$, $p < 0.001$, $\eta_p^2 = 0.77$]. However, the degree to which perceptual load affected Hit rates did not vary between tasks [$F(1,15) = 0.79$, $p = 0.78$, $\eta_p^2 = 0.05$] (see Figure 2).

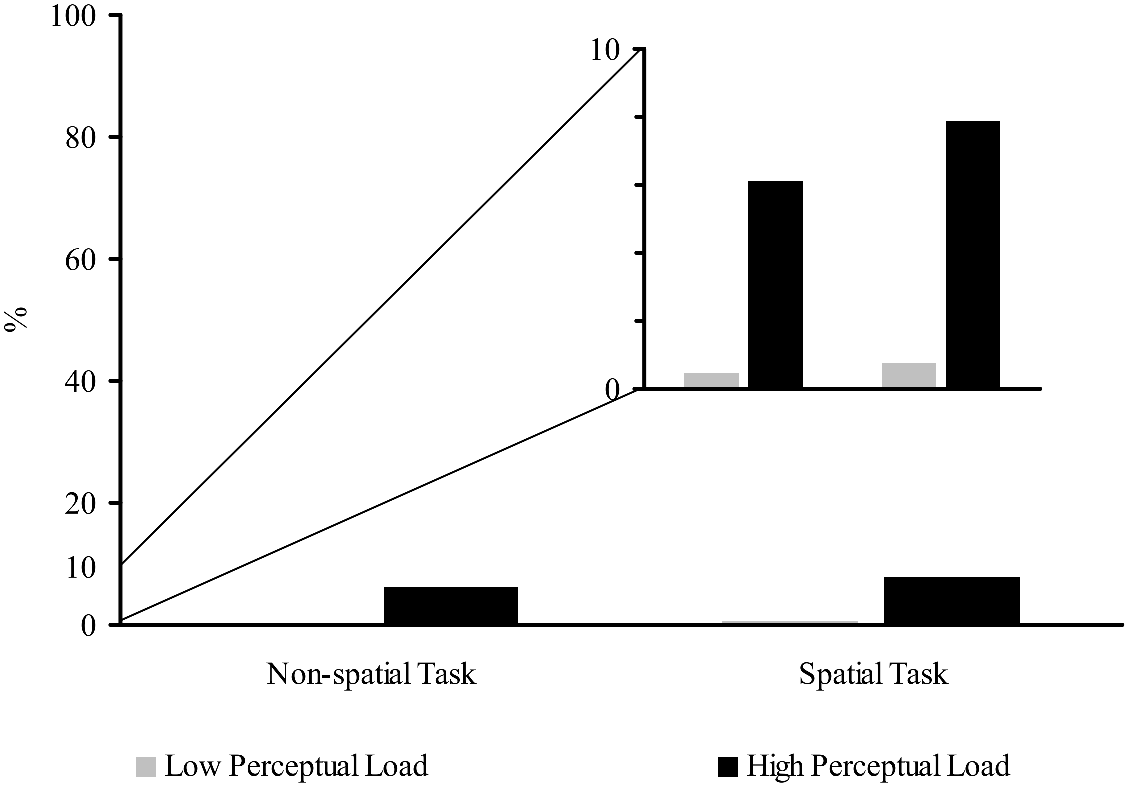
Figure 2. Mean Hit rates for the low and high perceptual load conditions in the spatial and non-spatial tasks.



False alarm (FA) rates were very low (less than 1% in all conditions), and were not different between the non-spatial and spatial tasks (0.016 % and 0.021 %, respectively; $F(1,15) = 1.06$, $p = 0.32$, $\eta_p^2 = 0.07$). FA rates were slightly but significantly higher when perceptual load was high (0.032 %) relative to when it was low (0.005 %) [$F(1,15) = 11.84$, $p = 0.004$, $\eta_p^2 = 0.44$]. As with Hit rates, perceptual load affected FA rates similarly in the two tasks [$F(1,15) = 0.41$, $p = 0.53$, $\eta_p^2 = 0.27$].

Although FA rates were low overall, an overwhelming majority of the FAs were in response to the presentation of a relevant standard stimulus so additional analyses were performed on these responses. The rate of FAs made in response to relevant standard stimuli was calculated by counting the number of responses made to these stimuli divided by the number of these stimuli that were presented. As found with the overall rates just reported, FAs made to relevant standard stimuli were similar in the non-spatial and spatial tasks (3.3 % and 4.3 %, respectively; $F(1,15) = 0.95$, $p = 0.35$, $\eta_p^2 = 0.06$), but were higher when perceptual load was high (7.0 %) relative to when it was low (0.06 %) [$F(1,15) = 13.63$, $p = 0.002$, $\eta_p^2 = 0.48$]. Consistent with the Hit rate and the (overall) FA rate, the degree to which perceptual load affected FA rates did not vary between tasks [$F(1,15) = 0.47$, $p = 0.50$, $\eta_p^2 = 0.30$] (See Figure 3).

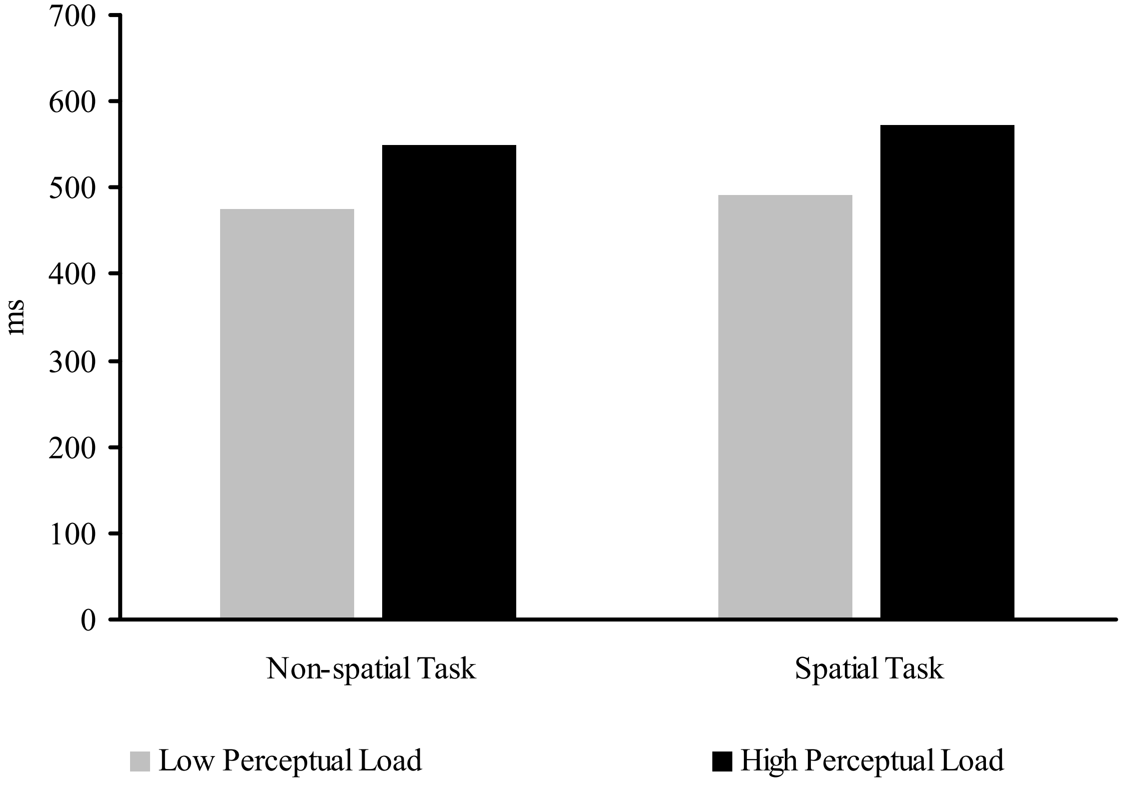
Figure 3. Mean false alarm rates for the low and high perceptual load conditions in the spatial and non-spatial tasks. Values represent the percentage of standard relevant stimuli to which subjects responded. The inset graph enlarges the scale in the 0% - 10% region.



1.*2 Reaction Time*

Subjects responded 20 ms slower to targets in the spatial task than they did in the non-spatial task [532 vs. 512 ms, respectively, *F*(1,15) = 26.50, $p < 0.001$, $\eta_p^2 = 0.64$] and responded 79 ms slower in the high perceptual load conditions relative to the low perceptual load conditions [562 vs. 483 ms, respectively, *F*(1,15) = 56.58, $p < 0.001$, $\eta_p^2 = 0.79$]. Importantly, and consistent with the Hit and FA results just described, the degree to which perceptual load affected RT did not vary between tasks [$F(1,15) = 0.17$, $p = 0.69$, $\eta_p^2 = 0.01$] (See Figure 4).

Figure 4. Mean reaction time (RT) to targets, in milliseconds (ms).



Taken together, subjects' behavioral performance, specifically lower performance in the high perceptual load condition relative to the low perceptual load condition as measured by Hit rate, false alarm rate, and reaction time, suggests that our manipulation of perceptual load was successful (Theeuwes, Kramer, & Kingstone, 2004). The possibility that this performance difference was due to greater distraction by irrelevant deviants in the high load condition is rendered unlikely when considered with the results from the pilot study (see Discussion).

Furthermore, the fact that perceptual load affected these performance measures similarly across conditions (i.e., the Task x Perceptual Load interactions were all non-significant) indicates that the difference in difficulty between the high and low load conditions was similar in the spatial and non-spatial tasks and as such makes our interpretation of the ERP results less equivocal (see Discussion) because any differences found between the tasks cannot be explained by a simple difference in difficulty between the tasks, or a difference in the amount of difficulty between the high and low perceptual load within each of the two tasks.

2. Electrophysiology

2.1 ERP morphology

The first observable ERP component in all tasks and conditions was a positive-going component which peaked at approximately 150 ms post-stimulus, and was maximal in amplitude at posterior electrodes. This is referred to as the P1 component, and is usually observed in visual tasks. Its modulation by attention in spatial cuing tasks has been demonstrated, but is less reliable than other ERP components (Posner & Dehaene, 1994).

The next component that was evident in the waveforms was a negative-going component, which peaked at approximately 200 ms post-stimulus, and was also maximal at posterior electrodes. This is referred to as the N1 component and like the P1 is usually observed in visual tasks. N1 is reliably affected by both spatial and non-spatial attention (Lange, Wijers, Mulder, & Mulder, 1998). Figures 36 – 39 display original and subtraction waveforms across the entire 64-channel electrode array from -100 to 250 ms post-stimulus.

Following the N1 was a second positive-going , and a second negative-going component which peaked at approximately 250 and 300 ms, respectively in the spatial task. These components have similar timing as the P2 and N2 components, such as found in the Lange et al.(1998) study. Consistent with past results, this temporal region of the waveform was modulated by attention. Figures 36 – 39 display original and subtraction waveforms across the entire 64-channel electrode array from -100 to 250 ms post-stimulus. Figures 30 – 35 display original and subtraction waveforms across the entire 64-channel electrode array from -100 to 500 ms post-stimulus, and Tables 2-9 report the results of all repeated measures ANOVAs.

2.2 Non-spatial task

2.2.1 Posterior electrode array

2.2.1.1 ERP activity surrounding the N1 component

ERPs at medial and lateral parietal/occipital (i.e., posterior) electrodes TP7/8, P5/6, P7/8, PO7/8, and O1/2, were more negative in response to relevant stimuli than to irrelevant stimuli during the 175 to 225 ms temporal window [$F(1,15) = 8.12$, $p = 0.012$, $\eta_p^2 = 0.35$]. However, this difference (i.e., the difference in N1 magnitude elicited by relevant and irrelevant stimuli, henceforth referred to as the ‘N1 attention effect’), was unaffected by perceptual load [$F(1,15) = 0.23$, $p = 0.640$, $\eta_p^2 = 0.02$] (see Figures 5-7).

Figure 5. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the low perceptual load condition (non-spatial task).

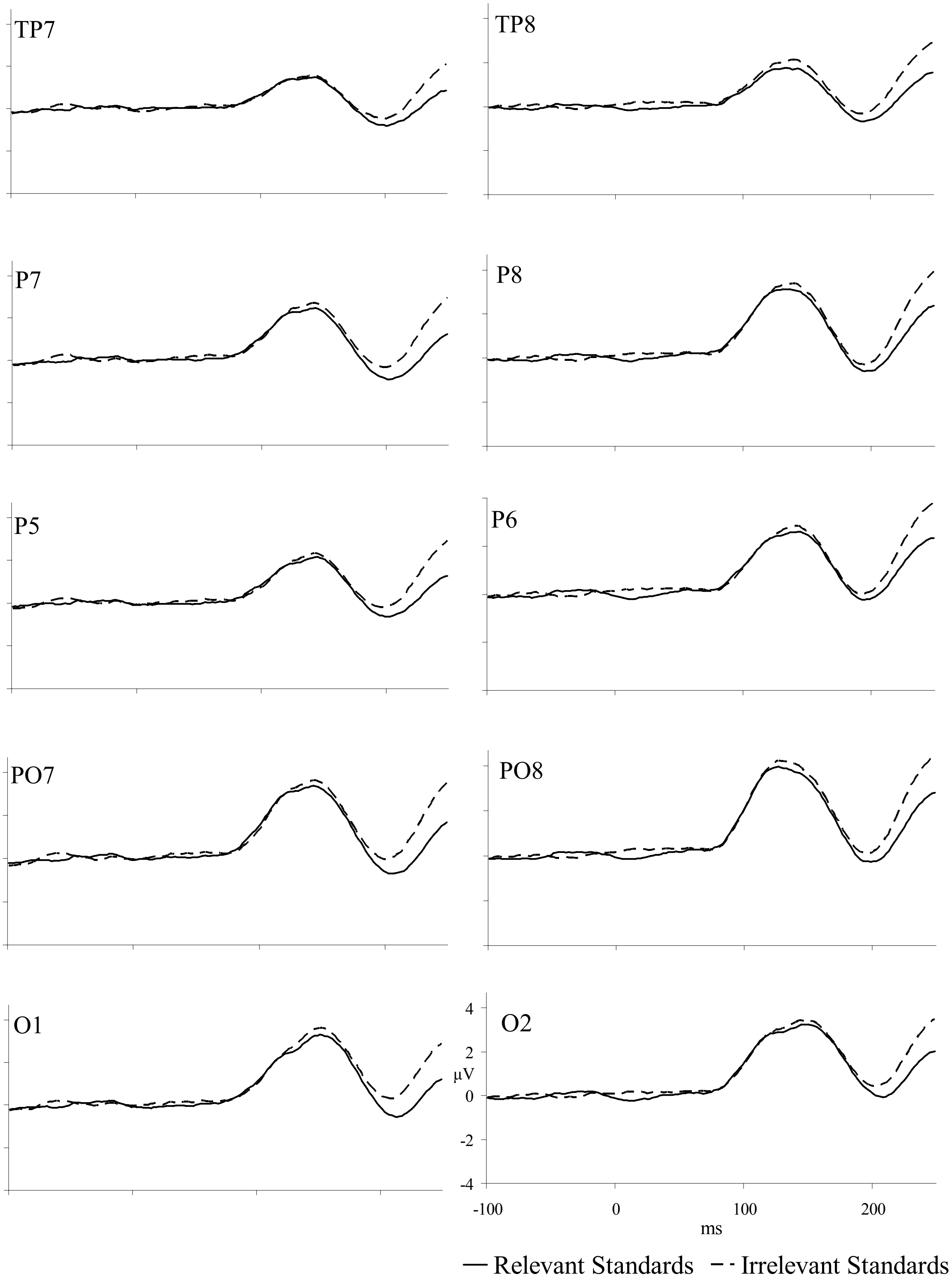


Figure **6**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the high perceptual load condition (non-spatial task).

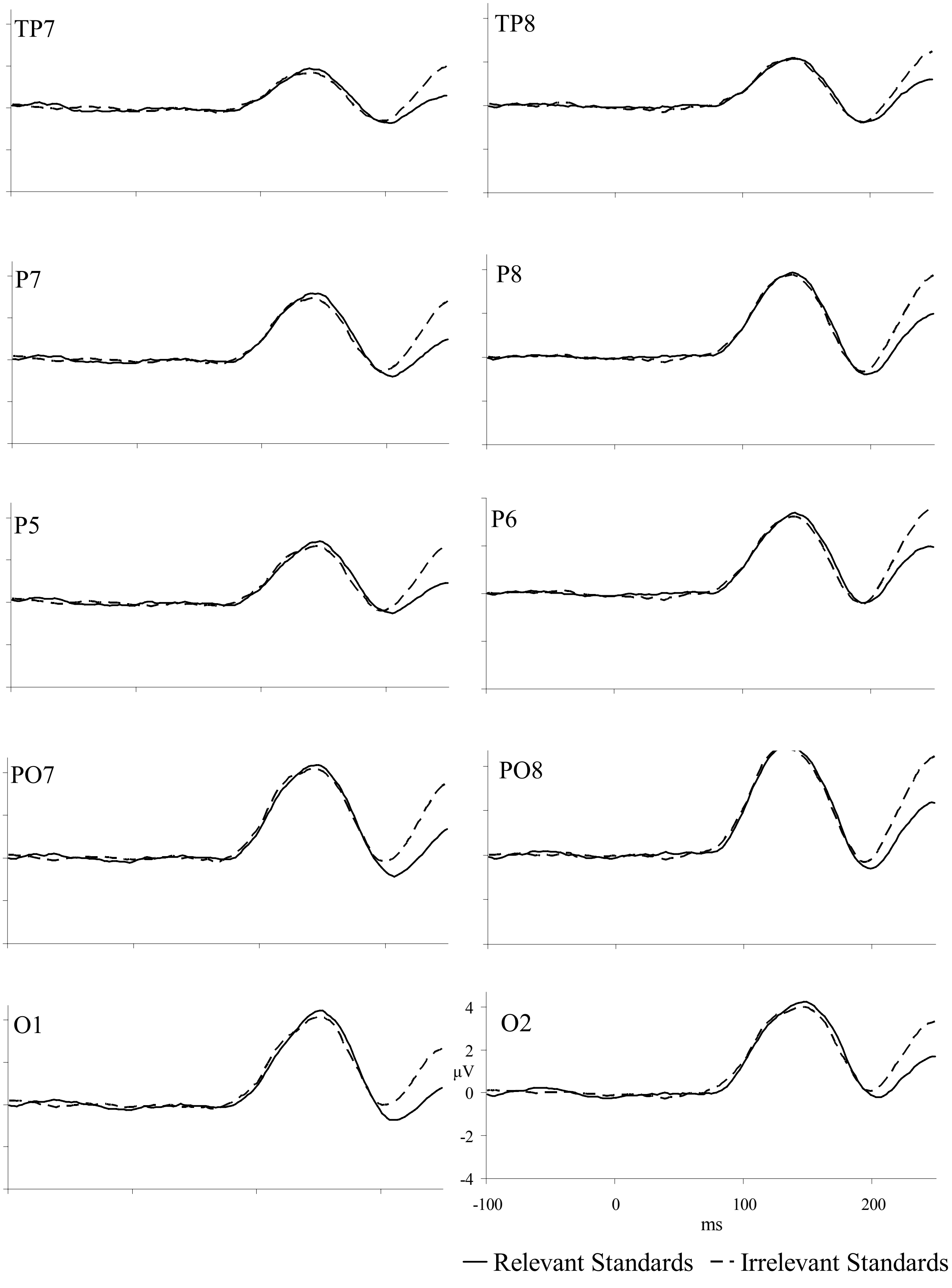
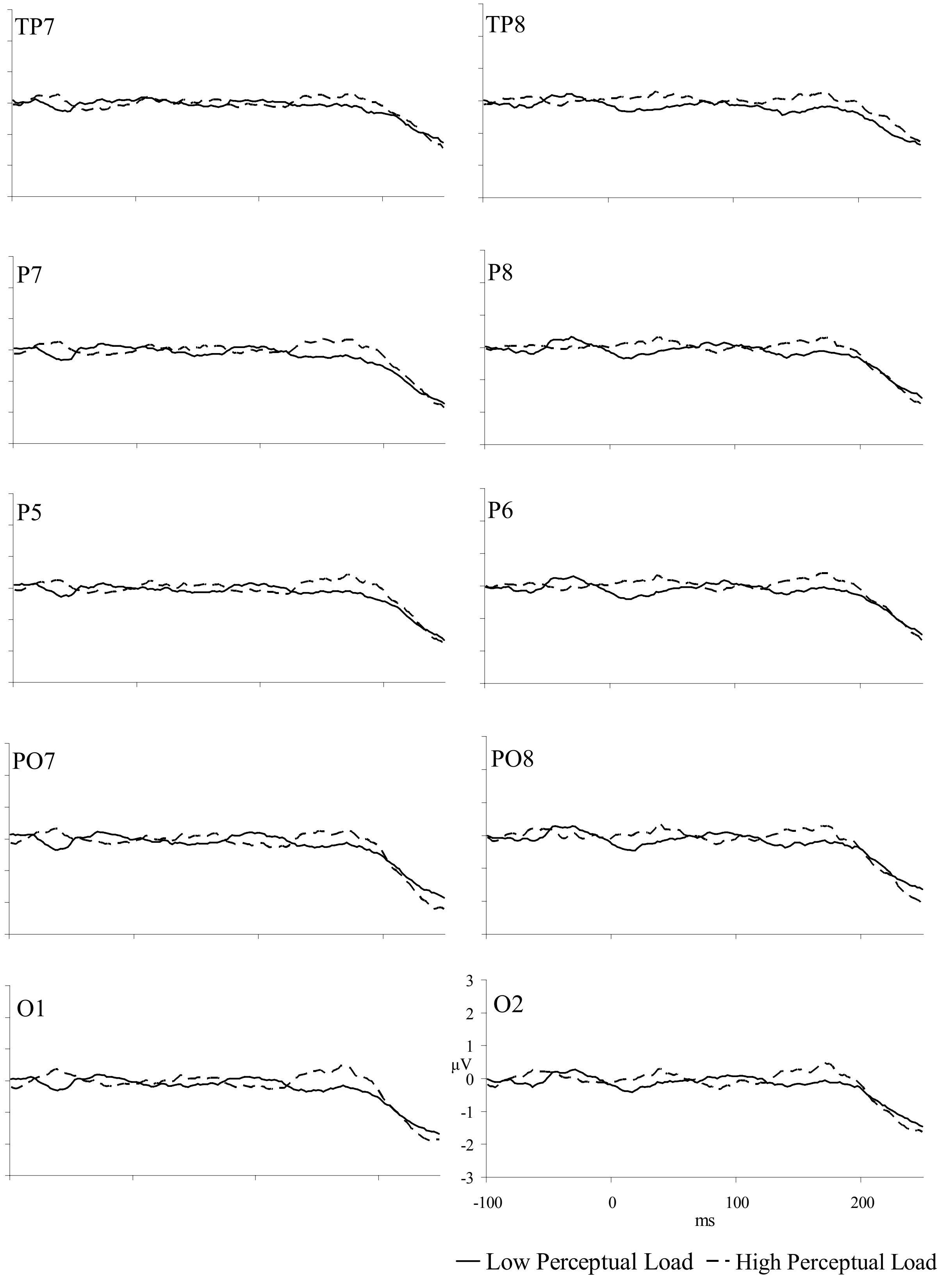


Figure 7. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of posterior electrodes (non-spatial task).



2.2.1.2 ERP activity surrounding the SN difference waveform

Likewise, ERPs at medial and lateral posterior electrodes were more negative in response to relevant stimuli than to irrelevant stimuli [$F(1,15) = 29.85$, $p < 0.001$, $\eta_p^2 = 0.67$] during the 275 – 325 ms temporal window. Importantly however, this effect (i.e., the magnitude of the SN) was significantly modulated by perceptual load [$F(1,15) = 5.08$, $p = 0.040$, $\eta_p^2 = 0.25$] (see Figures 8-10).

Figure **8**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the low perceptual load condition (non-spatial task).

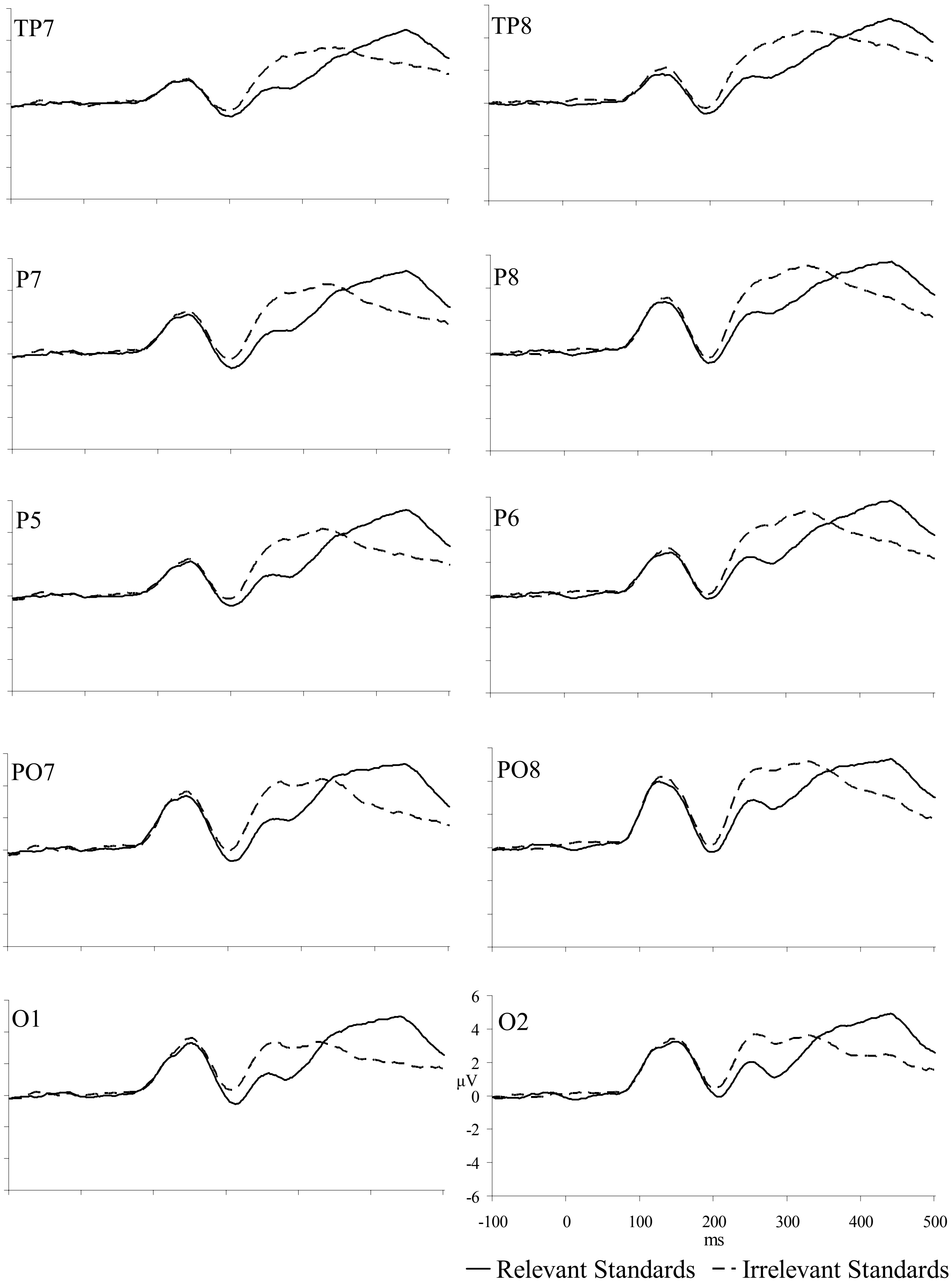


Figure **9**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the high perceptual load condition (non-spatial task).

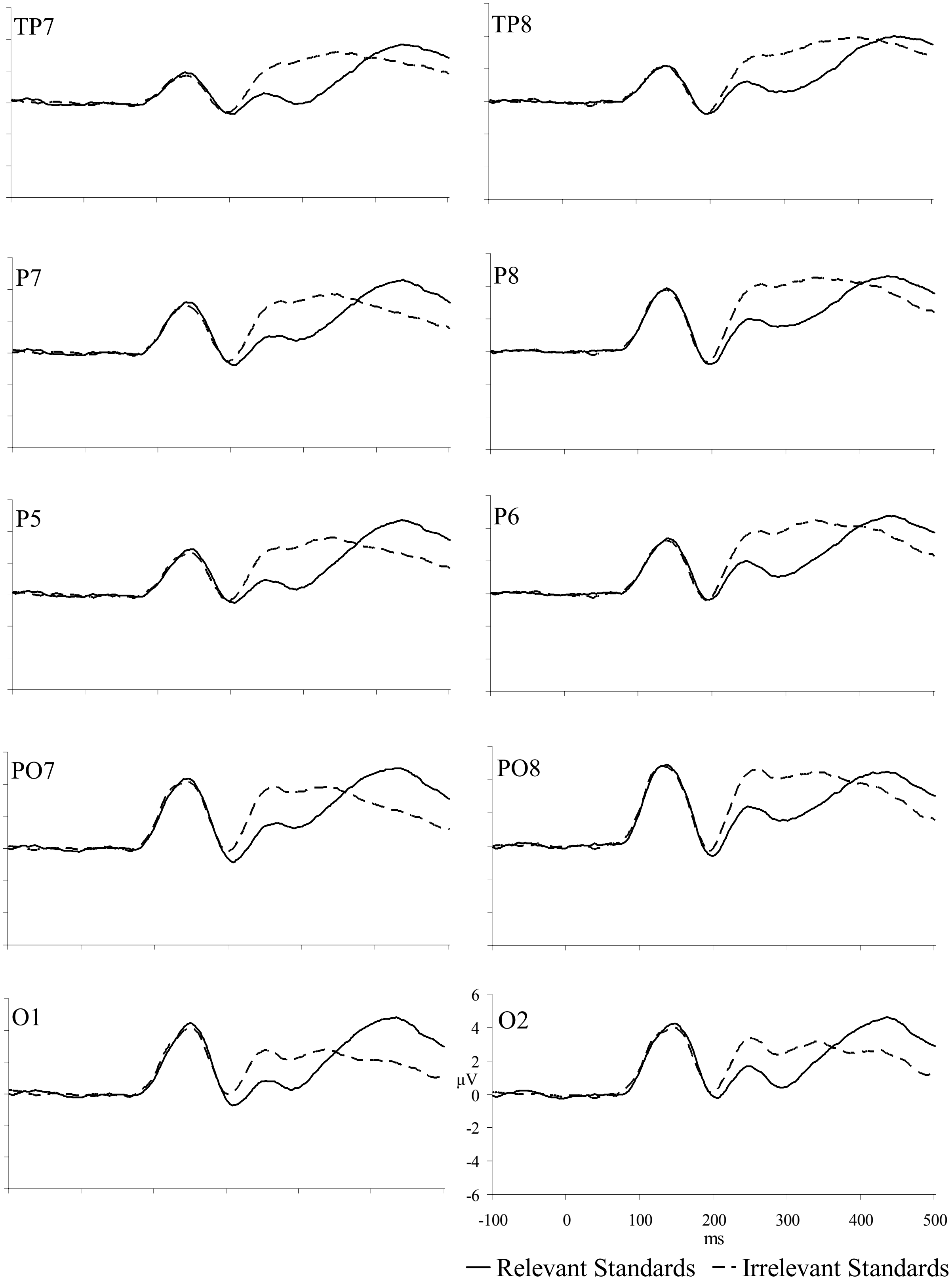
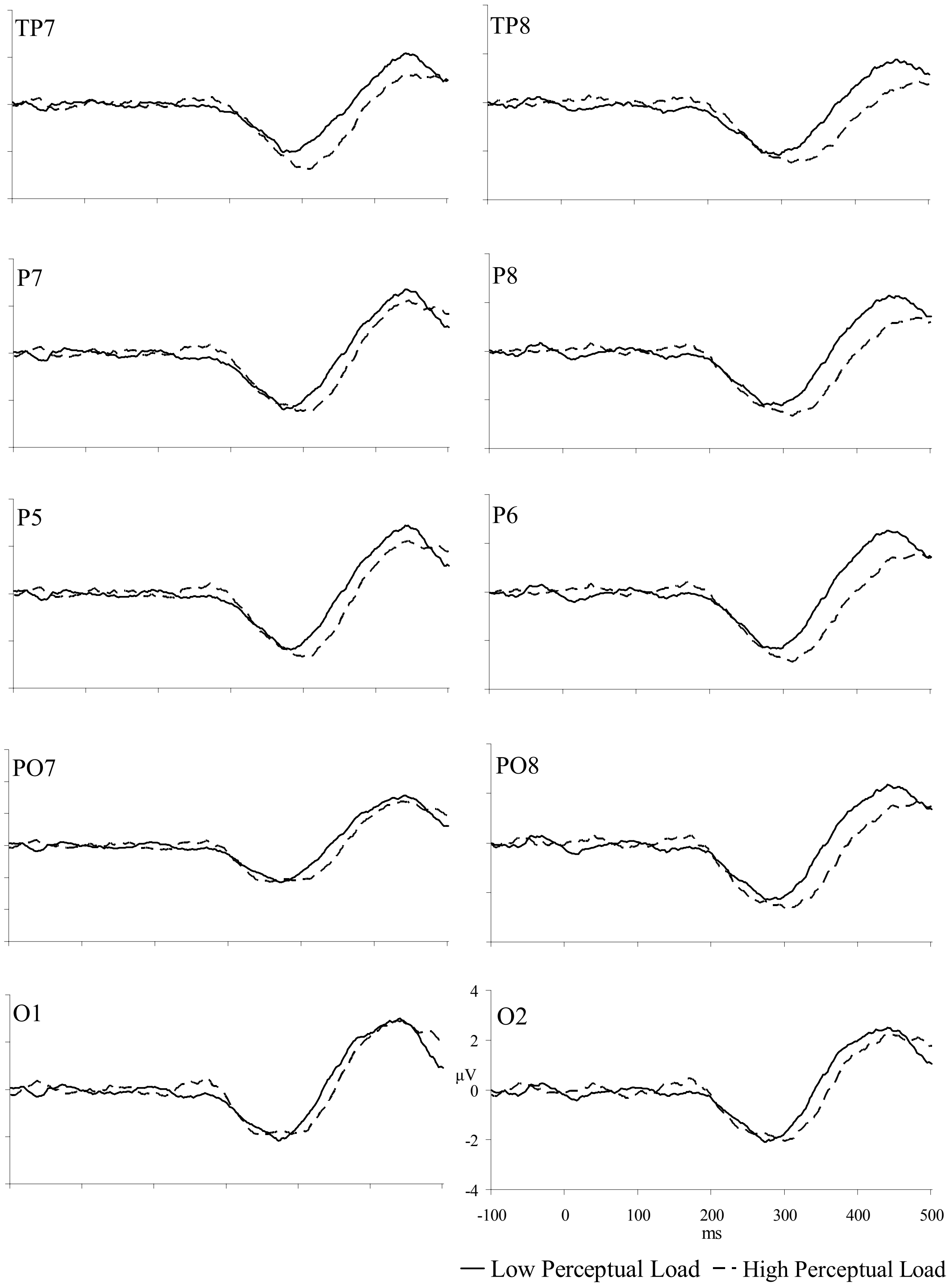


Figure **10**. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of posterior electrodes (non-spatial task).



2.2.2 Anterior electrode array

2.2.2.1 ERP activity surrounding the N1 component

In contrast to the findings from the posterior array, Stimulus Relevance (i.e., relevant vs. irrelevant stimuli) did not affect ERP activity surrounding the peak latency of the N1 at a corresponding set of medial and lateral frontal (i.e., anterior) electrodes (FP1/2, AF7/8, F5/6, F7/8, and FT7/8) [$F(1,15) = 1.00$, $p = 0.334$, $\eta_p^2 = 0.06$]. Likewise, the Perceptual Load x Stimulus Relevance interaction did not reach significance at these sites [$F(1,15) = 3.19$, $p = 0.094$, $\eta_p^2 = 0.18$] (see Figures 11-12).

Figure **11**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the low perceptual load condition (non-spatial task).

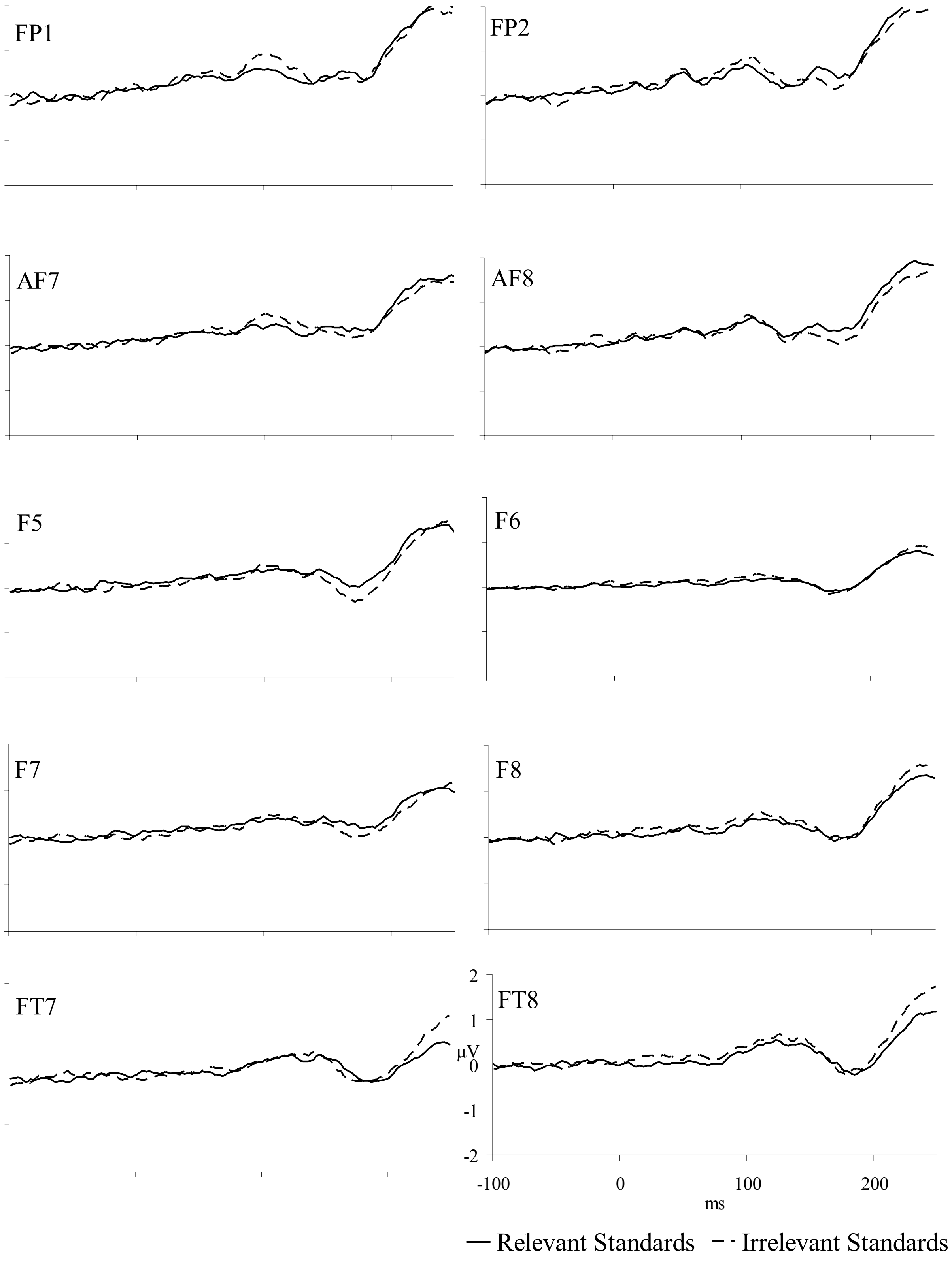
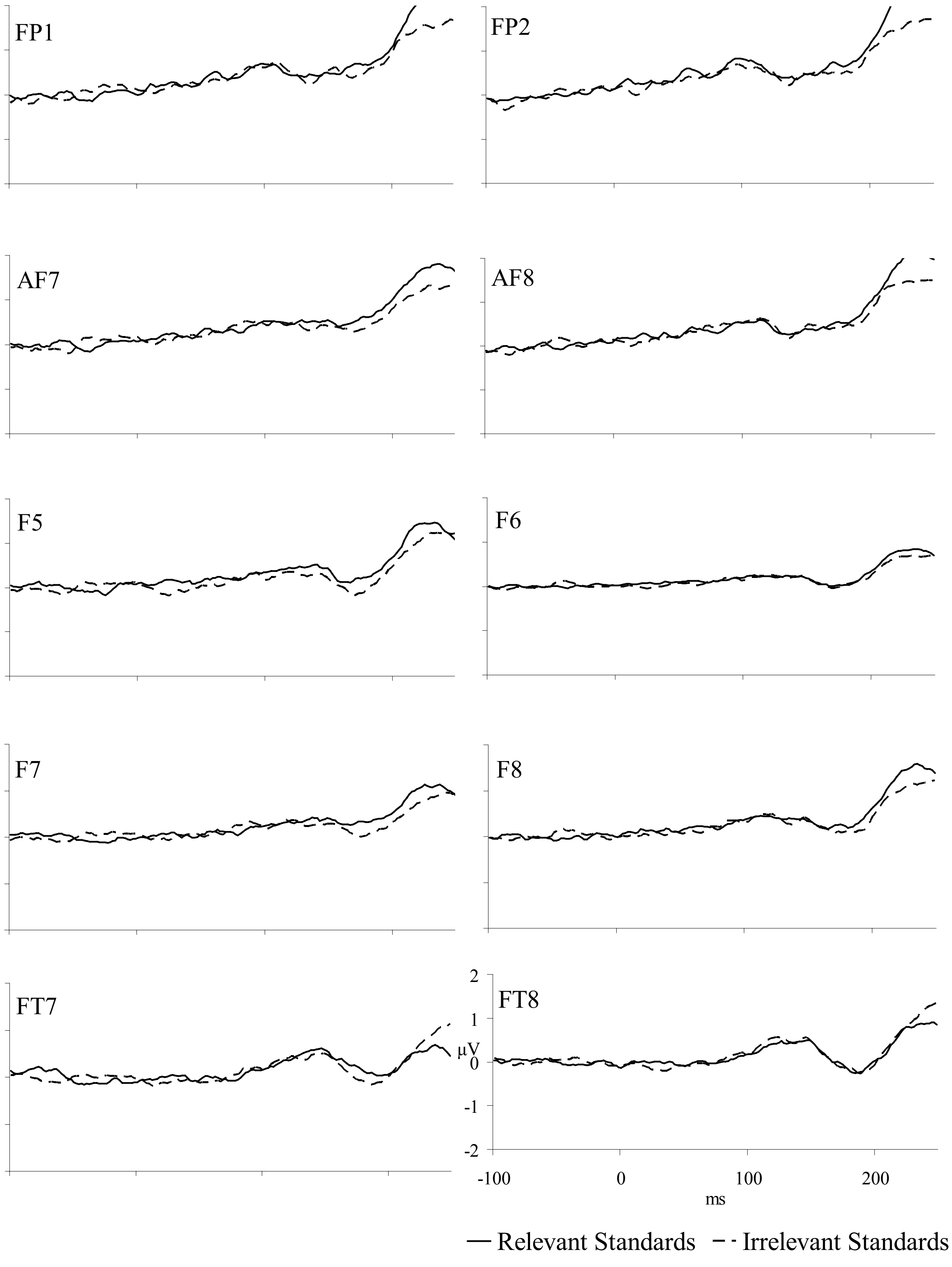


Figure **12**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the high perceptual load condition (non-spatial task).



2.2.2.2 ERP activity surrounding the SN difference waveform

Although ERPs were also more negative in response to relevant stimuli than to irrelevant stimuli [$F(1,15) = 29.18$ $p < 0.001$, $\eta_p^2 = 0.66$], perceptual load did not modulate this effect [$F(1,15) = 1.81$, $p = 0.199$, $\eta_p^2 = 0.11$] at the anterior electrode sites (see Figures 13-15).

Figure **13**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the low perceptual load condition (non-spatial task).

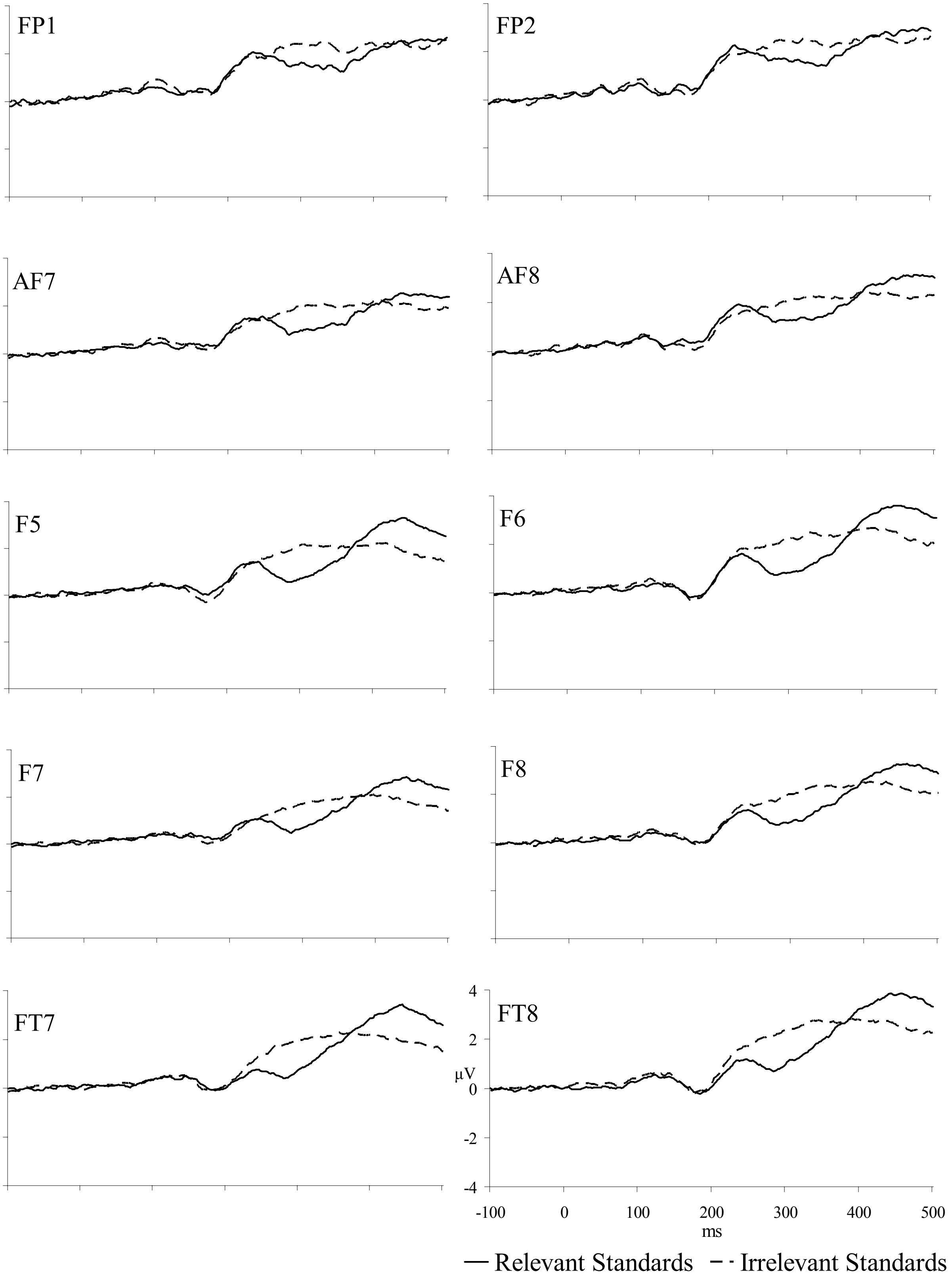


Figure **14**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the high perceptual load condition (non-spatial task).

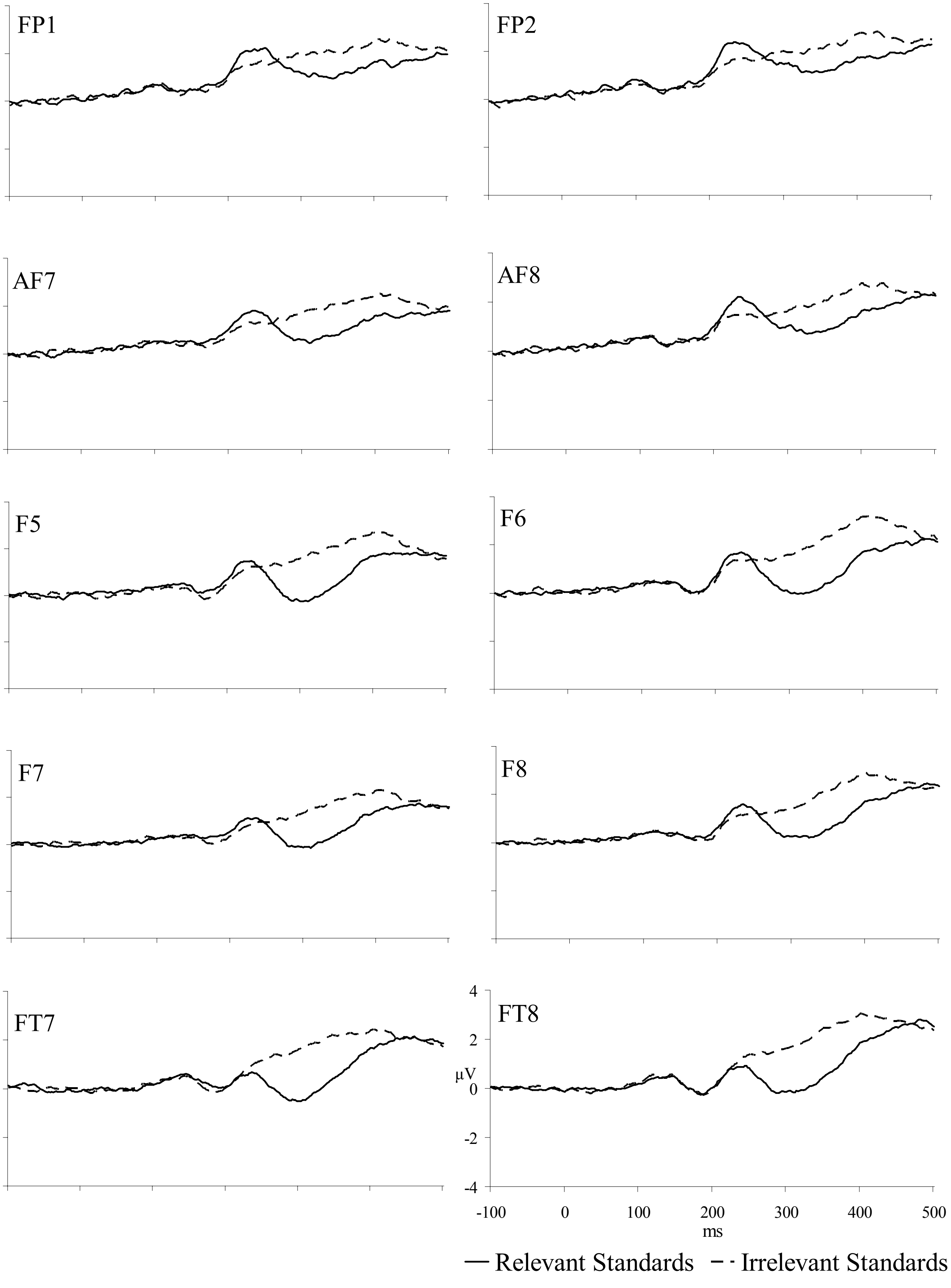
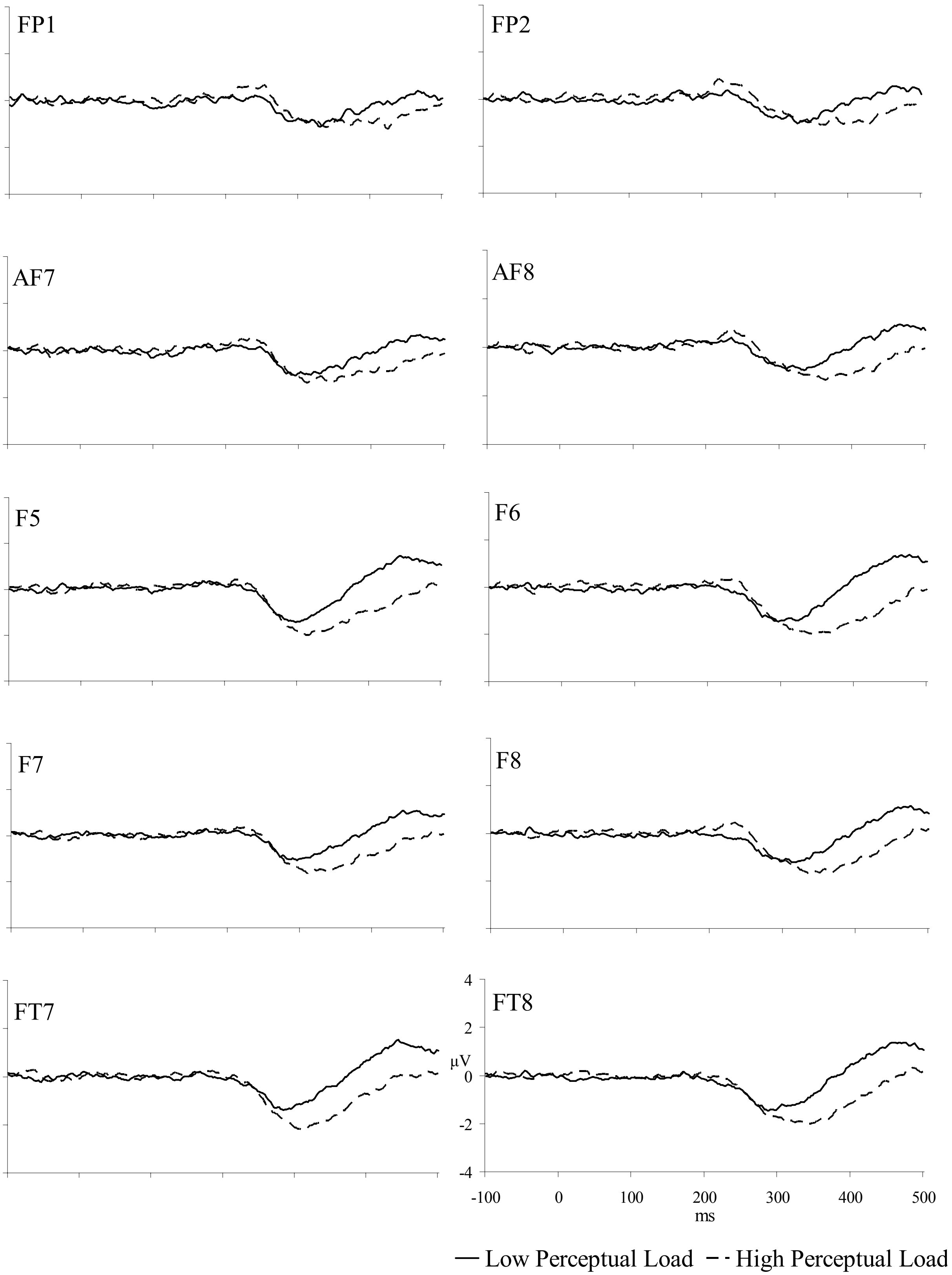


Figure 15. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of anterior electrodes (non-spatial task).



2.2.3 Comparisons of electrode arrays

2.2.3.1 ERP activity surrounding the N1 component

Since Perceptual Load did not significantly affect the degree to which Stimulus Relevance affected N1 amplitude at either Scalp Region, it is not surprising that the N1 attention effect was (not) modulated by perceptual load similarly at these two scalp regions [Scalp Region x Perceptual Load x Stimulus Relevance; $F(1,15) = 0.12$, $p = 0.731$ $\eta_p^2 = 0.01$] in the non-spatial task.

2.2.3.2 ERP activity surrounding the SN difference waveform

Even though Perceptual Load significantly affected SN magnitude at posterior but not anterior channels, the effect of perceptual load on SN amplitude did not differ significantly between these two scalp regions [Perceptual Load x Stimulus Relevance x Scalp Region; $F(1,15) = 1.91$, $p = 0.187$, $\eta_p^2 = 0.11$].

2.3 Spatial task

2.3.1 Posterior electrode array

2.3.1.1 ERP activity surrounding the N1 component

As found in the non-spatial task, the N1 component was more negative in response to relevant stimuli than to irrelevant stimuli at the posterior electrodes [$F(1,15) = 12.92$, $p = 0.003$, $\eta_p^2 = 0.46$]. However, in contrast to what was found in the non-spatial task, perceptual load significantly modulated this N1 attention effect [$F(1,15) = 10.54$, $p = 0.005$, $\eta_p^2 = 0.41$] (see Figures 16-18).

Figure **16**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the low perceptual load condition (spatial task).

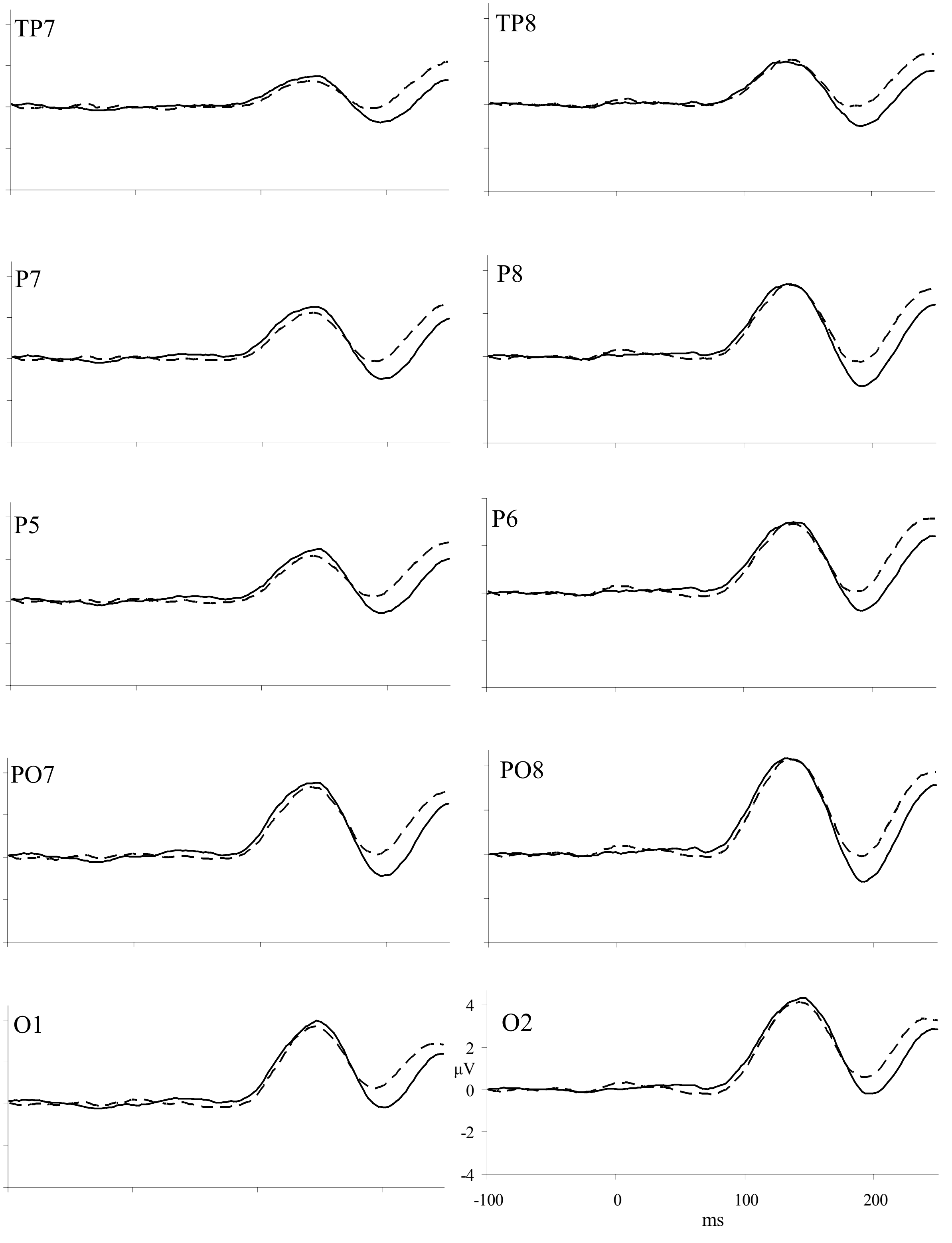


Figure 17. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the high perceptual load condition (spatial task).

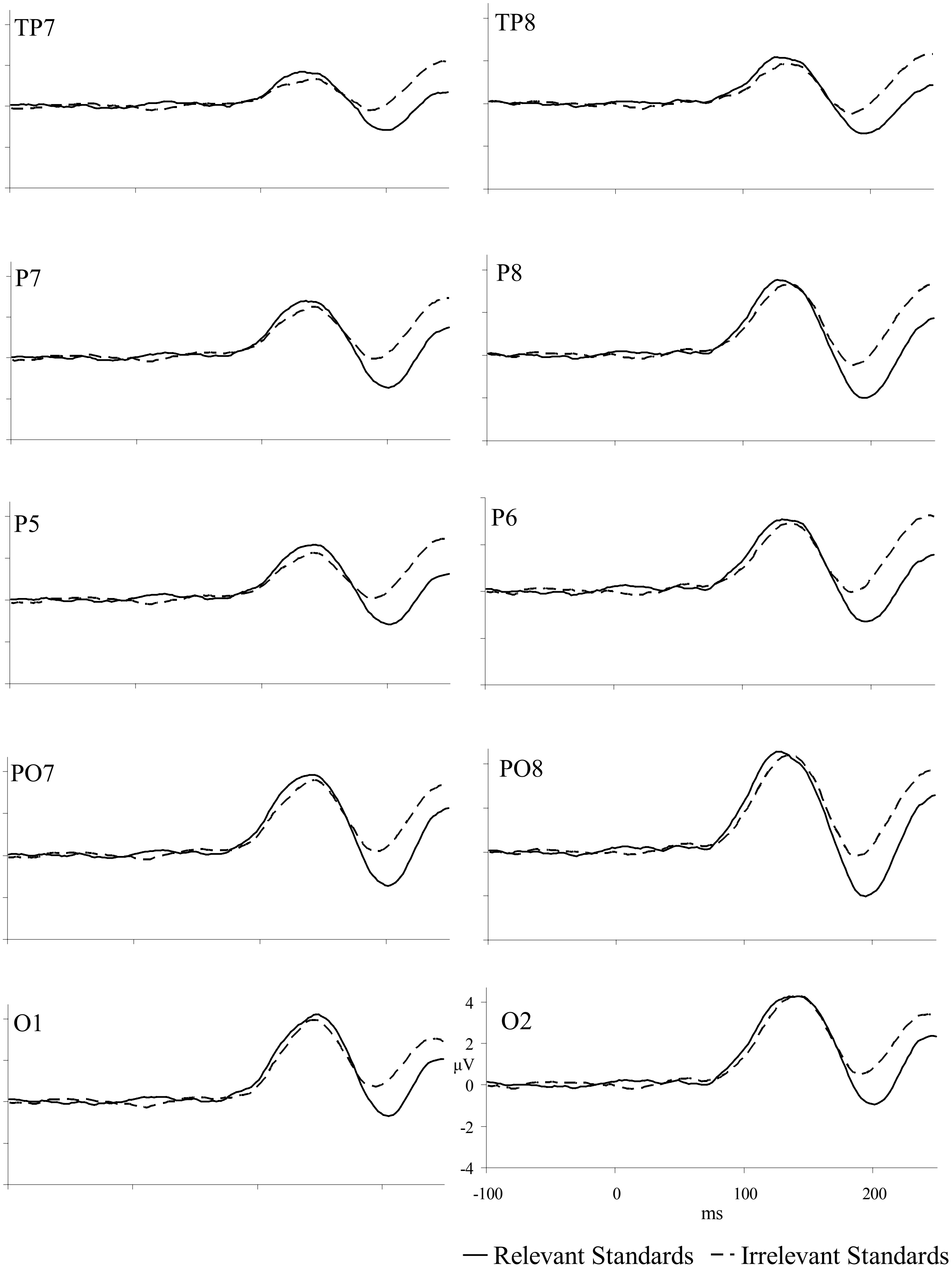
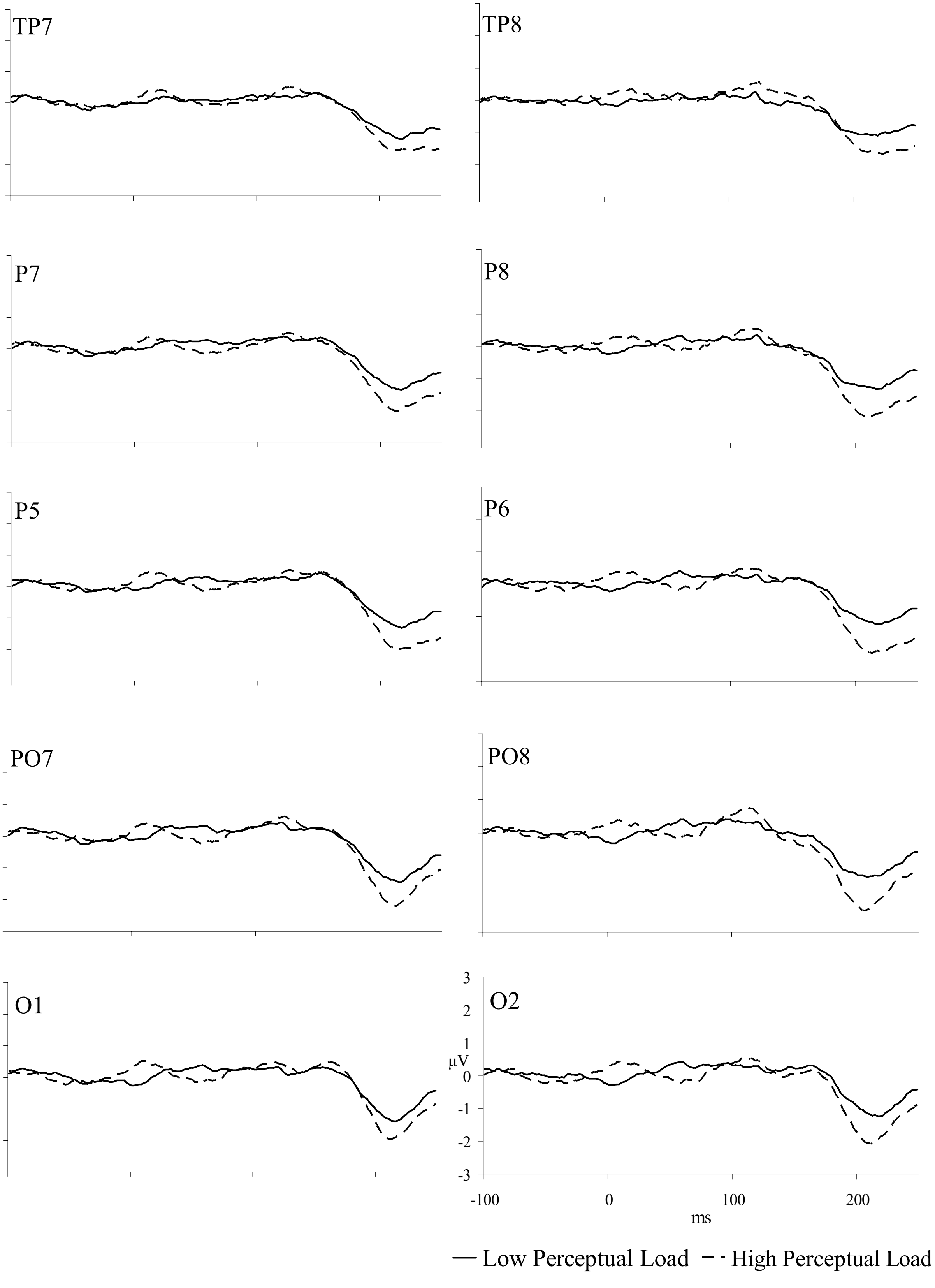


Figure **18**. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of posterior electrodes (spatial task).



2.3.1.2 ERP activity surrounding the SN difference waveform

ERPs during the later temporal window were more negative in response to relevant stimuli than to irrelevant stimuli at the posterior electrode array [$F(1,15) = 7.56$, $p = 0.015$, $\eta_p^2 = 0.34$]. Importantly, this effect (i.e., the SN) was significantly modulated by perceptual load [$F(1,15) = 36.18$, $p < 0.001$, $\eta_p^2 = 0.71$] at these sites (see Figures 19-21).

Figure **19**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the low perceptual load condition (spatial task).

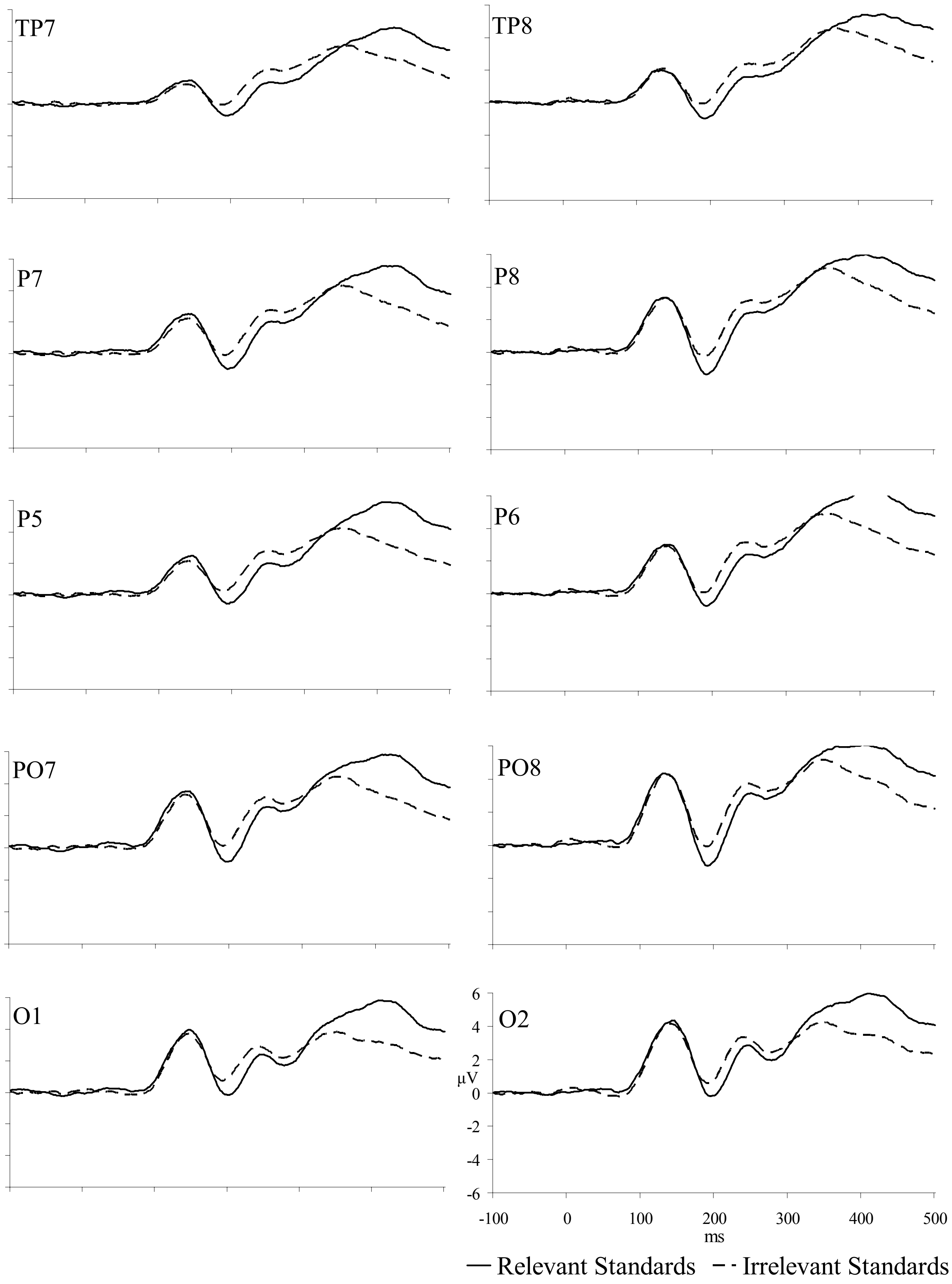


Figure **20**. Grand average ERP waveforms from an array of posterior electrodes, averaged from standard stimuli in the high perceptual load condition (spatial task).

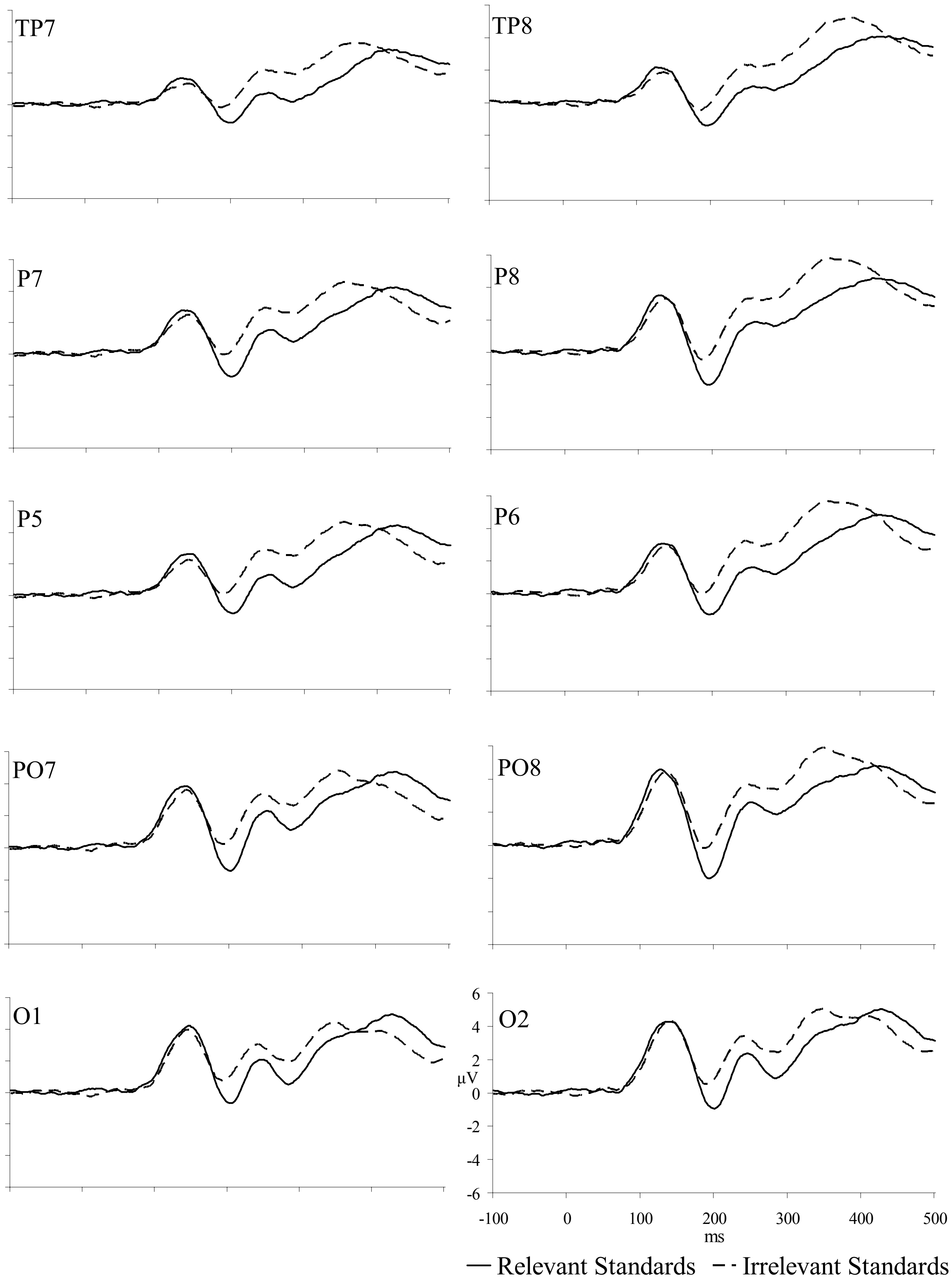
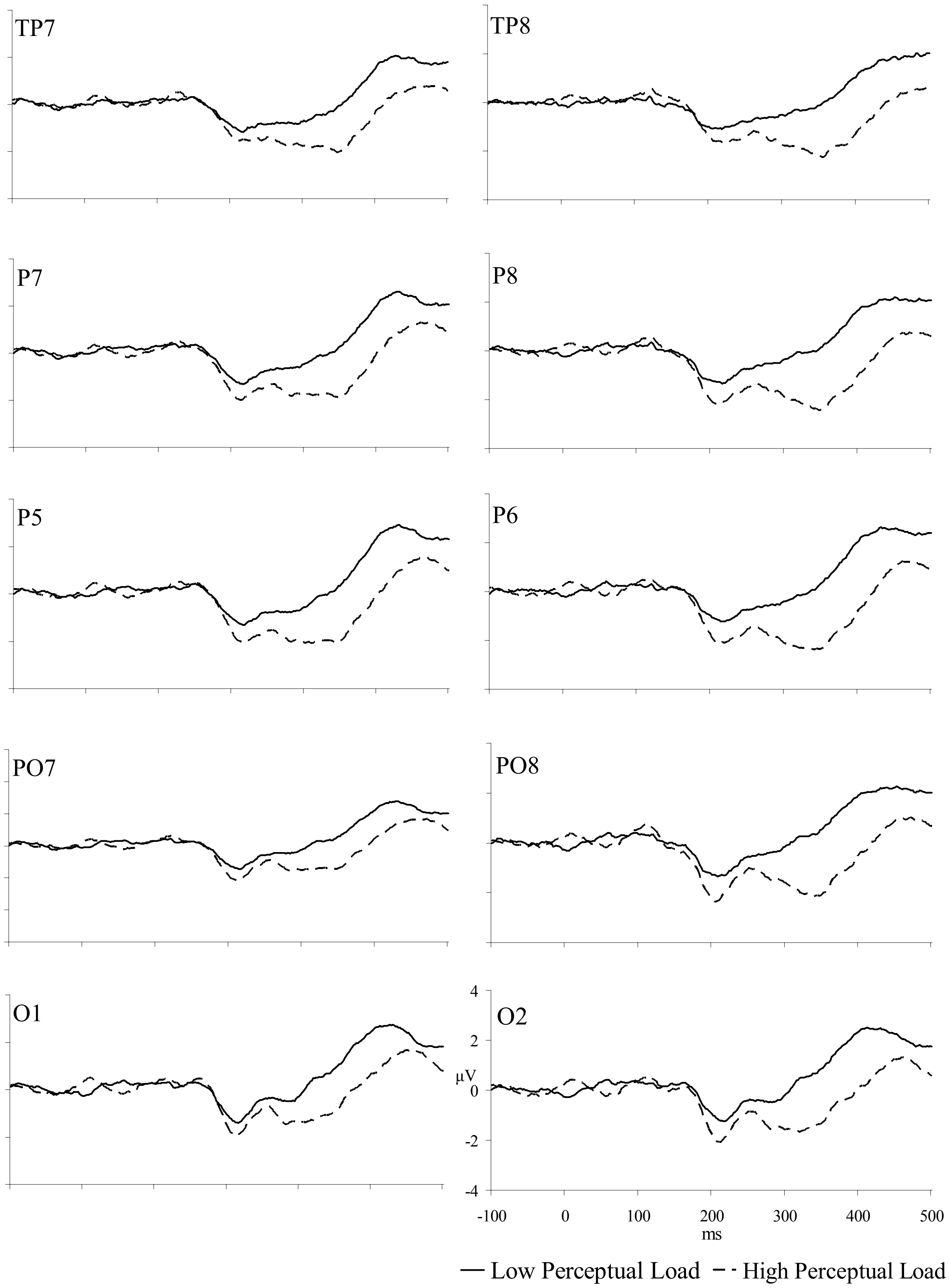


Figure **21**. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of posterior electrodes (spatial task).



2.3.2 Anterior electrode array

2.3.2.1 ERP activity surrounding the N1 component

The magnitude of the N1 was unaffected by Stimulus Relevance [$F(1,15) = 0.57$, $p = 0.460$, $\eta_p^2 = 0.04$]. Furthermore, Perceptual Load did not modulate this (lack of) effect [$F(1,15) = 0.003$, $p = 0.96$, $\eta_p^2 < 0.01$] (see Figures 22-23).

Figure **22**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the low perceptual load condition (spatial task).

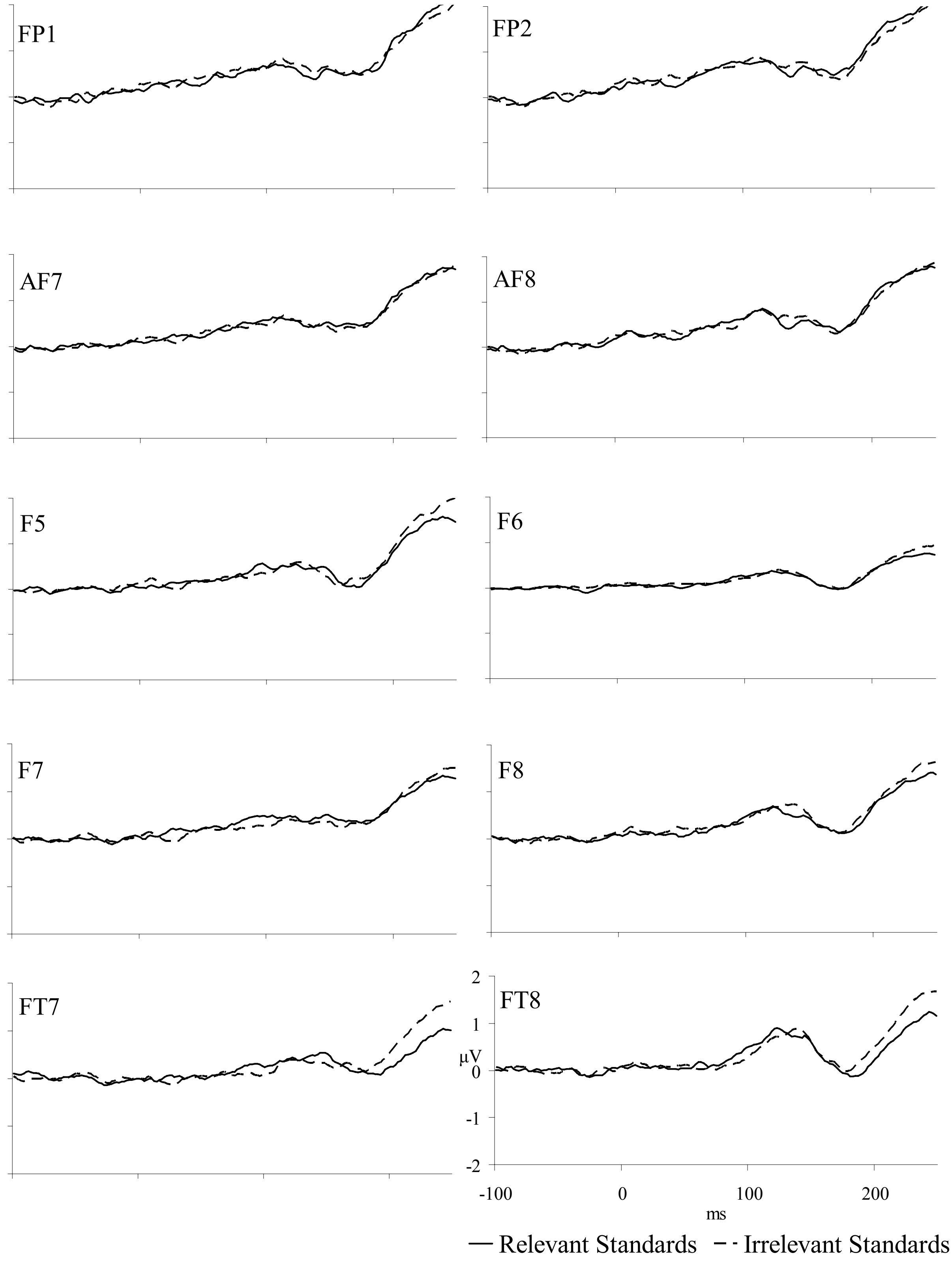
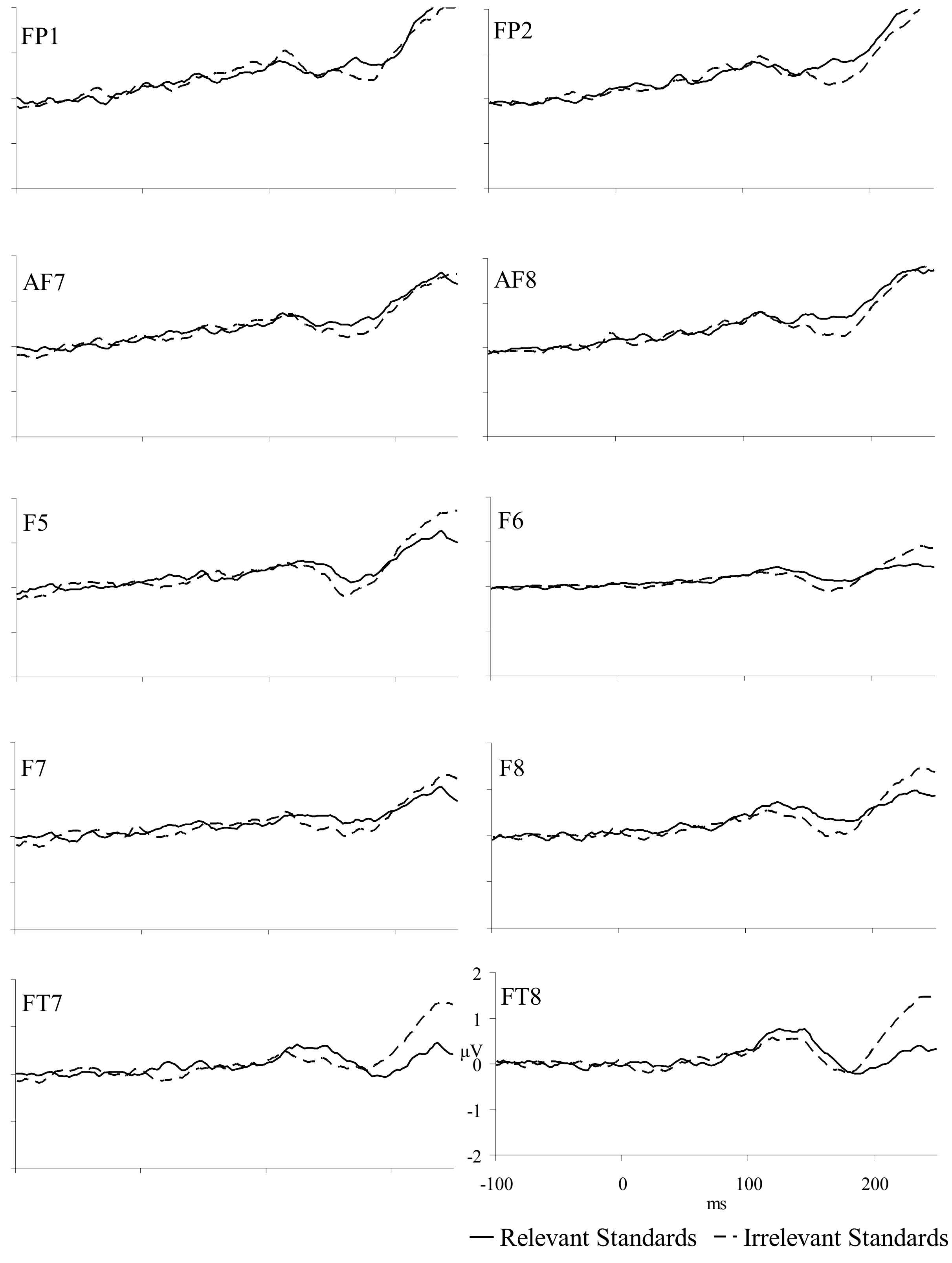


Figure **23**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the high perceptual load condition (spatial task).



2.3.2.2 ERP activity surrounding the SN difference waveform

By contrast, ERPs at the anterior array were more negative in response to relevant stimuli than they were to irrelevant stimuli [$F(1,15) = 41.61$, $\mathrm{p} < 0.001$, $\eta_{\mathrm{p}}^2 = 0.74$] and this difference (i.e., the SN) was affected by perceptual load [$F(1,15) = 7.04$, $p = 0.018$, $\eta_{\mathrm{p}}^2 = 0.32$] (see Figures 24-26).

Figure **24**. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the low perceptual load condition (spatial task).

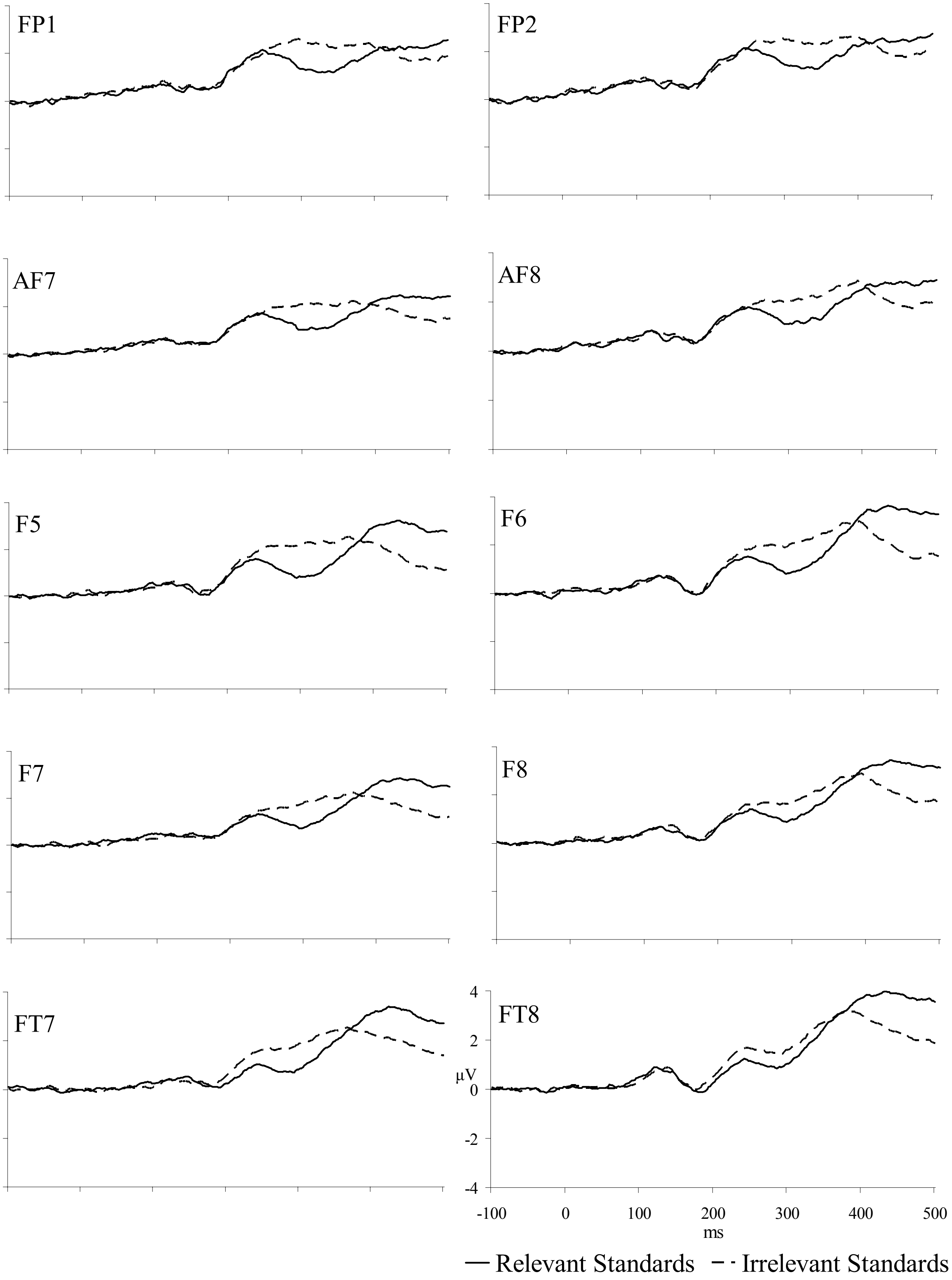


Figure 25. Grand average ERP waveforms from an array of anterior electrodes, averaged from standard stimuli in the high perceptual load condition (spatial task).

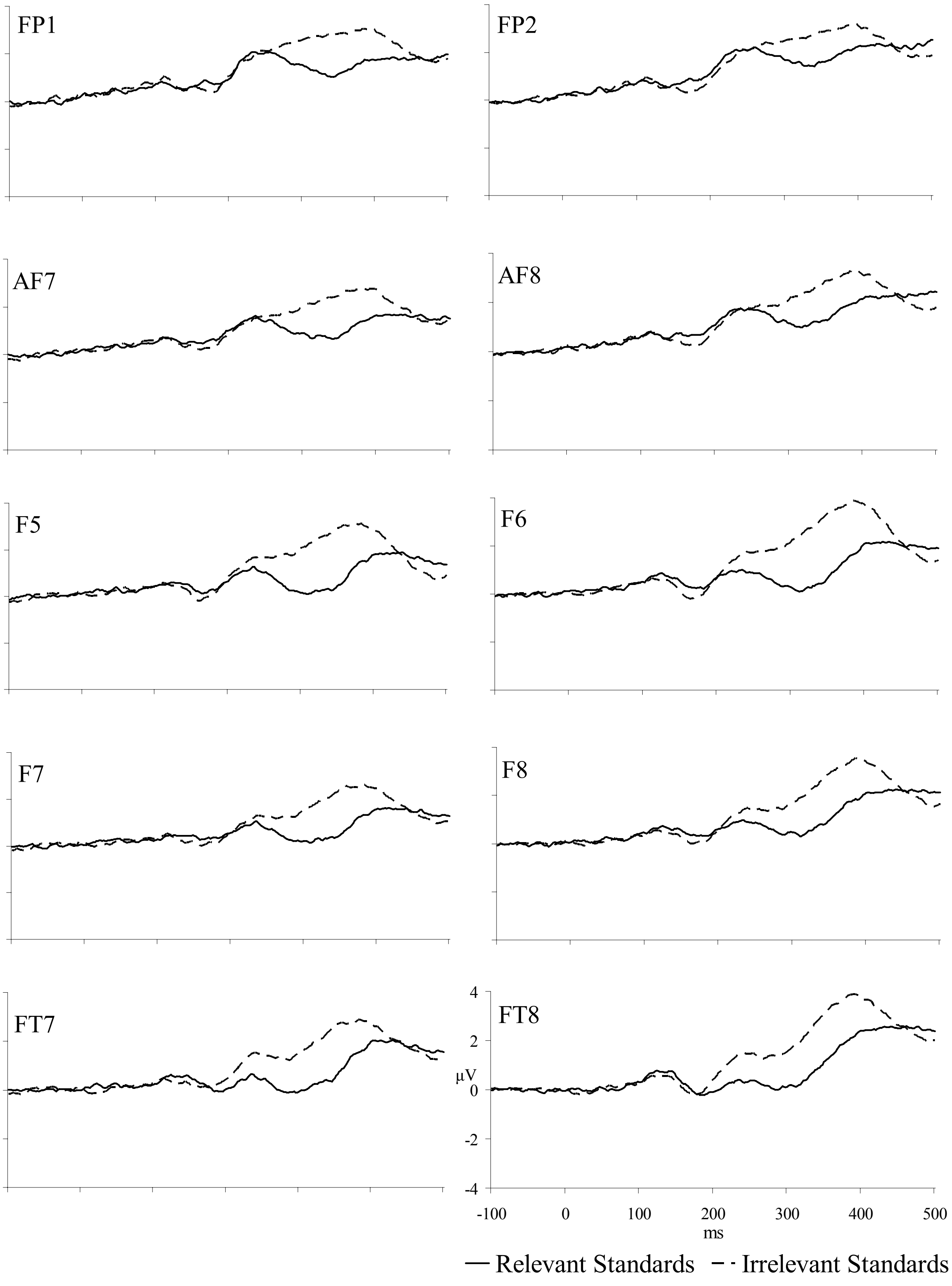
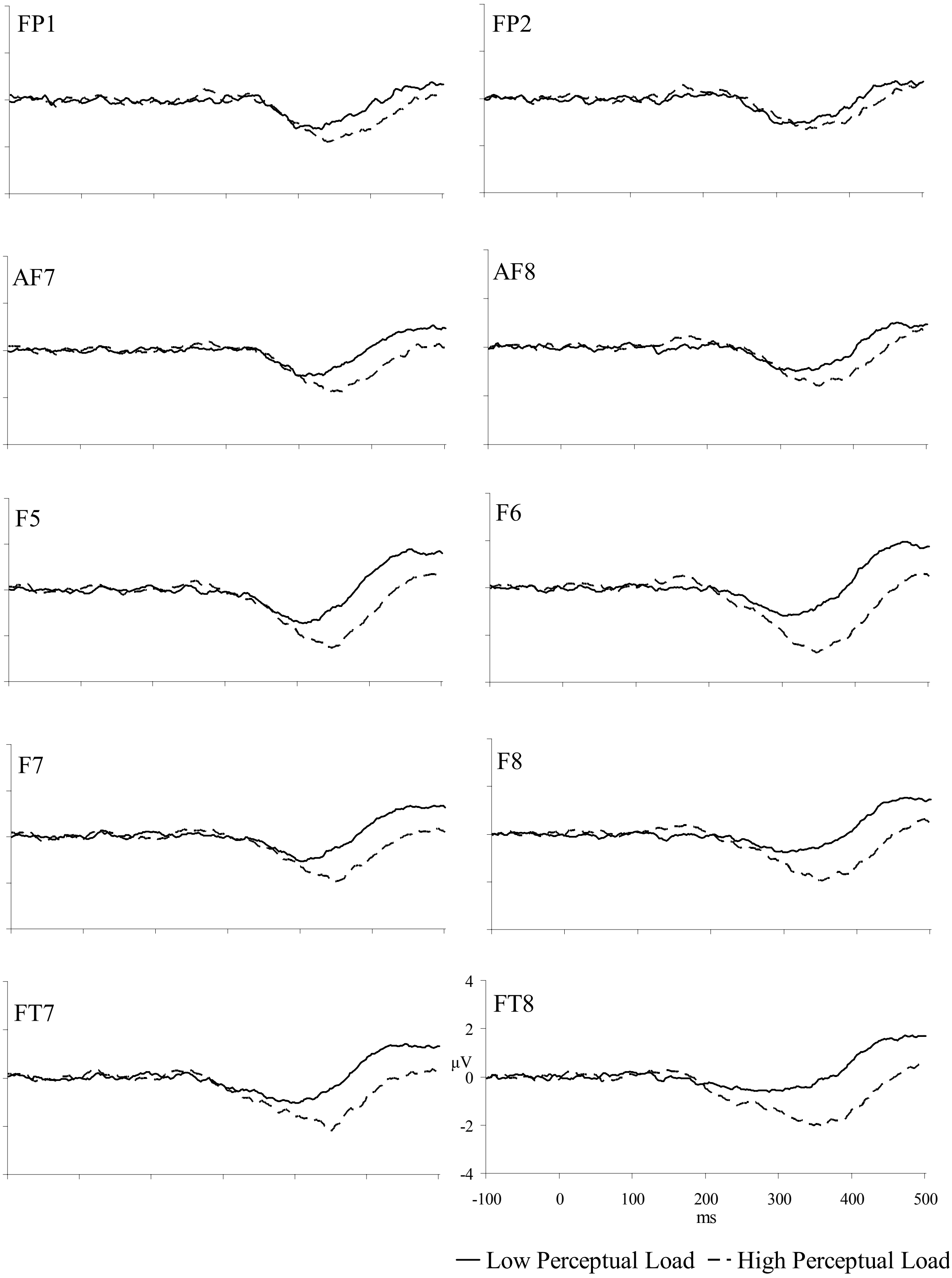


Figure **26**. Grand average ERP subtraction waveforms (relevant minus irrelevant standards) from an array of anterior electrodes (spatial task).



2.3.3 Comparisons of electrode arrays

2.3.3.1 ERP activity surrounding the N1 component

As expected, given that perceptual load affected the N1 attention effect at posterior but not anterior electrodes in the spatial task, the modulation of the N1 attention effect by perceptual load differed significantly across the two scalp regions [Scalp Region x Perceptual Load x Stimulus Relevance; $F(1,15) = 9.21$, $p = 0.008$, $\eta_p^2 = 0.38$].

2.3.3.2 ERP activity surrounding the SN difference waveform

Although Perceptual Load significantly affected SN amplitude at both of the electrode arrays, it did so to a significantly larger degree at posterior sites in the spatial task [Perceptual Load x Stimulus Relevance x Scalp Region interaction; [$F(1,15) = 31.50$, $p < 0.001$, $\eta_p^2 = 0.68$].

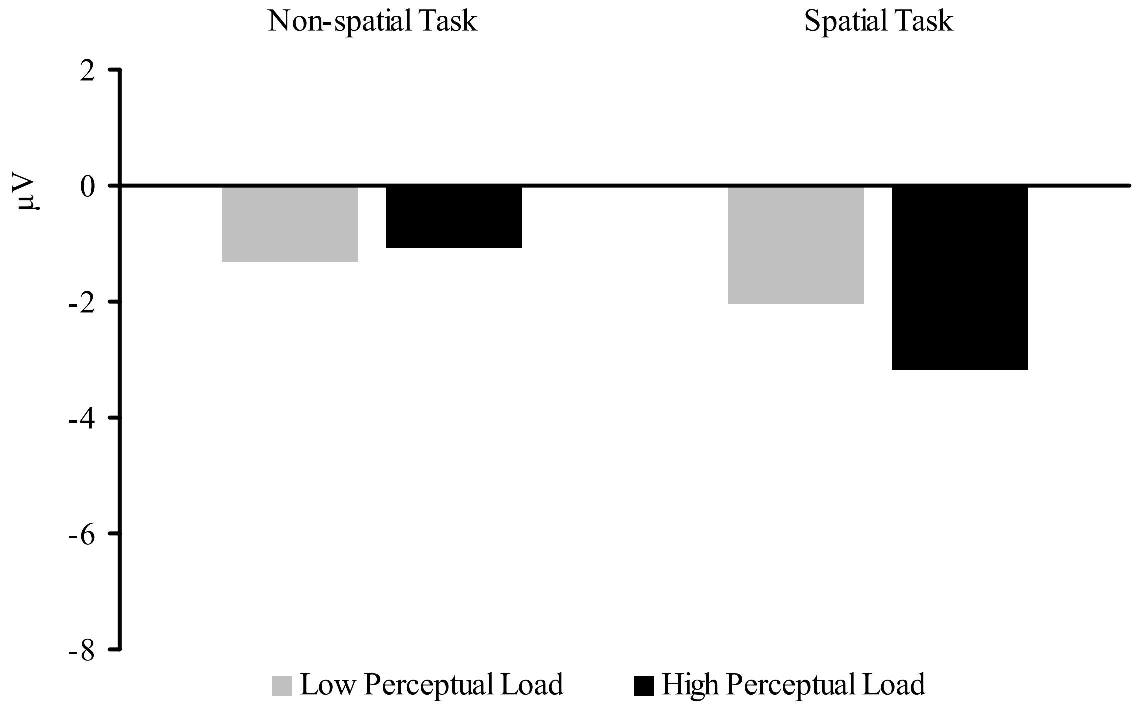
2.4 Comparisons across tasks

2.4.1 Posterior electrode array

2.4.1.1 ERP activity surrounding the N1 component

The N1 attention effect appeared to be somewhat larger in the spatial task than the non-spatial task, although the trend only approached significance [$F(1,15) = 4.50$, $p = 0.051$, $\eta_p^2 = 0.23$*]. Nevertheless, due to the fact that the N1 attention effect was significantly affected by perceptual load in the spatial but not the non-spatial task, the Task x Perceptual Load x Stimulus Relevance interaction was significant [*$F(1,15) = 9.33$, $p = 0.008$, $\eta_p^2 = 0.38$*] (see Figure 27).*

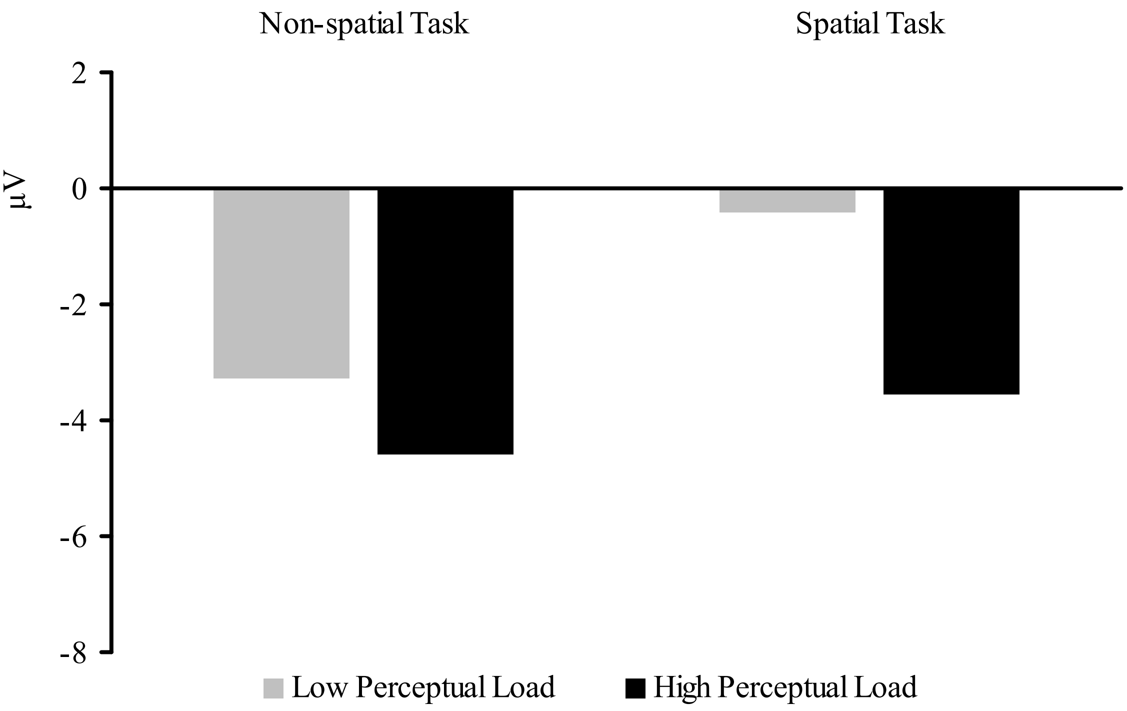
Figure 27. Bars represent the differences in N1 amplitude (in μV) elicited by relevant and irrelevant standard stimuli, averaged across the posterior electrode array at the 175 - 225 ms epoch.



2.4.1.2 ERP activity surrounding the SN difference waveform

Importantly, the degree to which perceptual load affected the magnitude of the SN at posterior electrodes differed significantly between the non-spatial and spatial tasks. Specifically, perceptual load affected SN magnitude to a greater degree in the spatial task than in the non-spatial task [$F(1,15) = 7.55$, $p = 0.015$, $\eta_p^2 = 0.34$]. It is important to note that this finding obtained despite the fact that SN amplitude was larger in the non-spatial task at these electrodes [Task x Stimulus Relevance; $F(1,15) = 9.79$, $p = 0.007$, $\eta_p^2 = 0.40$] (see Figure 28).

Figure **28**. Bars represent SN amplitudes (in µV), averaged across the posterior electrode array at the 275 - 325 ms epoch.

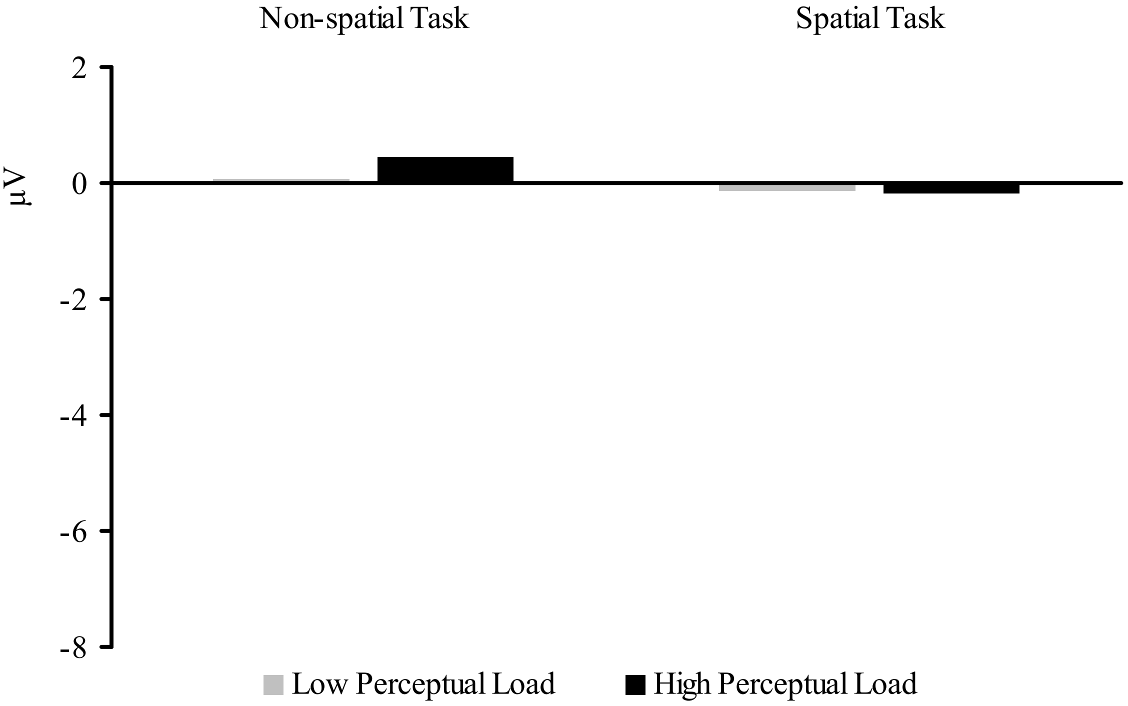


2.4.2 Anterior electrode array

2.4.2.1 ERP activity surrounding the N1 component

These findings were not obtained at the anterior array, where the N1 attention effect did not reach significance overall [$F(1,15) = 0.12$, $p = 0.730$, $\eta_p^2 = 0.01$] and did not differ between the tasks [$F(1,15) = 1.28$, $p = 0.276$, $\eta_p^2 = 0.08$]. In addition, perceptual load had a similar (lack of) effect on the N1 attention effect in the two tasks [$F(1,15) = 0.74$, $p = 0.403$, $\eta_p^2 = 0.05$] (see Figure 29).

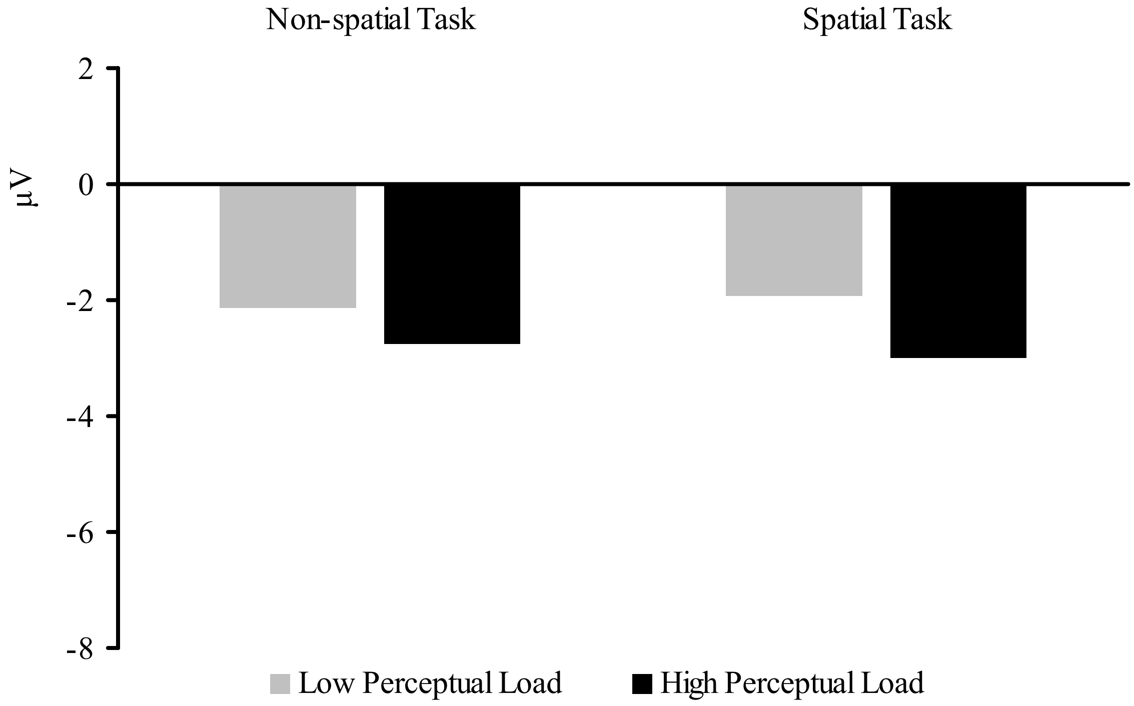
Figure **29**. Bars represent the differences in N1 amplitude (in µV) elicited by relevant and irrelevant standard stimuli, averaged across the anterior electrode array at the 175 - 225 ms epoch.



2.4.2.2 ERP activity surrounding the SN difference waveform

Despite the fact that perceptual load affected the magnitude of the SN in the spatial but not in the non-spatial task at the anterior electrode array, overall perceptual load did not affect the magnitude of the SN differently across tasks at these sites [Perceptual Load x Stimulus Relevance x Task interaction; $F(1,15) = 0.50, p = 0.488, \eta_p^2 = 0.03$] (see Figure 30).

Figure **30**. Bars represent SN amplitudes (in μV), averaged across the anterior electrode array at the 275 - 325 ms epoch.



2.4.3 Comparisons of electrode arrays

2.4.3.1 ERP activity surrounding the N1 component

The N1 attention effect increased with perceptual load more in the spatial task than it did in the non-spatial task at the posterior electrode sites, but did not do so at the anterior sites. Despite this, the Scalp Region x Task x Perceptual Load x Stimulus Relevance interaction only approached significance [$F(1,15) = 4.23$, $p = 0.058$, $\eta_p^2 = 0.22$], but did not reach significance as it did in the 275 - 325 ms epoch. However, this and the other findings discussed above regarding the differences between the posterior array and anterior array suggest that our effects are not due to nonspecific effects of our manipulations. Rather, they demonstrate that the pattern of modulation of putative attentional selection-related ERP effects by perceptual load that we found at the expected electrode locations was not found at other locations as well (see Discussion).

2.4.3.2 ERP activity surrounding the SN difference waveform

SN magnitude increased with perceptual load significantly more in the spatial task than it did in the non-spatial task, but did so only at the posterior electrode sites and not the anterior sites [Scalp Region x Task x Perceptual Load x Stimulus Relevance; $F(1,15) = 9.62$, $p = 0.007$, $\eta_p^2 = 0.39$]. This is important because it demonstrates that the effect of perceptual load on the SN that we found at the posterior electrodes, which were selected *a priori* and based upon known attentional modulations of ERPs described in the literature, was not found at corresponding frontal sites. This was as predicted, since the cognitive demands were not different between the two tasks, as demonstrated by the behavioral data above. This double dissociation provides stronger evidence of the phenomenon being described than would reporting only the posterior effects without analysis of the effects at frontal, or other appropriate, electrode sites (Weissman & Woldorff, 2005).

Table **3**. ANOVA results for factors Perceptual Load, Task, Stimulus Relevance, and Scalp Region at each of the time windows. All df = 1,15.

	175 - 225 ms		275 - 325 ms	
Source	*F*	*p*	*F*	*p*
Task	0.28	0.606	0.46	0.510
Perc. Load	0.57	0.462	14.06**	0.002
Stim. Rel.	10.59**	0.005	43.69**	<0.001
Scalp Reg.	1.44	0.249	8.49*	0.011
Scalp Reg. x Task	0.05	0.826	0.03	0.866
Scalp Reg. x Perc. Load	0.58	0.456	2.89	0.110
Task x Perc. Load	1.37	0.260	1.99	0.178
Scalp Reg. x Stim. Rel.	19.17**	0.001	0.58	0.458
Task x Stim. Rel..	3.83	0.069	5.59*	0.032
Perc. Load x Stim. Rel.	0.27	0.609	20.59**	<0.001
Scalp Reg. x Task x Perc. Load	0.02	0.891	0.001	0.974
Scalp Reg. x Task x Stim. Rel.	3.38	0.086	8.21*	0.012
Scalp Reg. x Perc. Load x Stim. Rel.	4.38	0.055	14.01**	0.002
Task x Perc. Load x Stim. Rel.	5.01*	0.039	3.63	0.076
Scalp Reg. x Task x Perc. Load x Stim. Rel.	4.23	0.058	9.62**	0.007

* $p < 0.05$, ** $p < 0.01$

Table **4**. ANOVA results for factors Perceptual Load, Stimulus Relevance, and Scalp Region, for each of the two tasks, at the 175 – 225 ms time window. All df = 1,15.

	Non-spatial task.		Spatial task.	
Source	*F*	*p*	*F*	*p*
Perc. Load	0.04	0.849	1.20	0.291
Stim. Rel.	2.19	0.160	10.85**	0.005
Scalp Reg.	1.40	0.255	1.33	0.267
Scalp Reg. x Perc. Load	0.193	0.666	0.95	0.344
Scalp Reg. x Stim. Rel.	19.95**	<0.001	13.69**	0.002
Perc. Load x Stim. Rel.	0.866	0.367	3.64	0.076
Scalp Reg. x Perc. Load x Stim. Rel.	0.12	0.731	9.21**	0.008

* $p < 0.05$, ** $p < 0.01$

Table **5**. ANOVA results for factors Perceptual Load, Stimulus Relevance, and Task, for each of the two electrode arrays at the 175 – 225 ms time window. All df = 1,15.

	Posterior Array		Anterior Array	
Source	*F*	*p*	*F*	*p*
Perc. Load	0.79	0.392	0.104	0.751
Stim. Rel.	15.19**	0.001	0.123	0.730
Task	0.21	0.657	0.312	0.585
Task. x Perc. Load	0.52	0.485	2.78	0.116
Task x Stim. Rel.	4.50	0.051	1.28	0.276
Perc. Load x Stim. Rel.	1.41	0.253	1.03	0.327
Task x Perc. Load x Stim. Rel.	9.33**	0.008	0.74	0.403

* $p < 0.05$, ** $p < 0.01$

Table **6**. ANOVA results for factors Perceptual Load, Stimulus Relevance, and Scalp Region, for each of the two tasks at the 275 – 325 ms time window. All df = 1,15.

	Non-spatial task.		Spatial task.	
Source	*F*	*p*	*F*	*p*
Perc. Load	11.17**	0.004	8.33*	0.011
Stim. Rel..	48.56**	<0.001	23.77**	<0.001
Scalp Reg.	5.61*	0.032	12.30**	0.003
Scalp Reg. x Perc. Load	1.36	0.262	4.95*	0.042
Scalp Reg. x Stim. Rel.	3.58	0.078	0.41	0.532
Perc. Load x Stim. Rel.	4.26	0.057	24.21**	<0.001
Scalp Reg. x Perc. Load x Stim. Rel.	1.91	0.187	31.50**	<0.001

* p < 0.05, ** p < 0.01

Table **7**. ANOVA results for factors Perceptual Load, Stimulus Relevance, and Task, for each of the two electrode arrays at the 275 – 325 ms time window. All df = 1,15.

	Posterior Array		Anterior Array	
Source	*F*	*p*	*F*	*p*
Perc. Load	9.48**	0.008	10.36**	0.006
Stim. Rel.	20.52**	<0.001	46.01**	<0.001
Task	0.28	0.607	0.73	0.408
Task. x Perc. Load	0.82	0.379	3.24	0.091
Task. x Stim. Rel.	9.79**	0.007	<0.001	0.987
Perc. Load x Stim. Rel.	25.49**	<0.001	7.04*	0.018
Task x Perc. Load x Stim. Rel.	7.55*	0.015	0.50	0.488

* p < 0.05, ** p < 0.01

Table **8**. ANOVA results for factors Perceptual Load and Stimulus Relevance at each electrode array, for each of the two tasks at the 175 – 225 ms time window. All df = 1,15.

	Posterior				Anterior			
	Non-spatial task		Spatial task		Non-spatial task		Spatial task	
Source	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Perc. Load	0.14	0.718	1.26	0.280	0.04	0.845	0.82	0.380
Stim. Rel.	8.12*	0.012	12.92**	0.003	1.00	0.334	0.57	0.460
Perc. Load x Stim. Rel.	0.23	0.640	10.54**	0.005	3.19	0.094	0.003	0.955

* $p < 0.05$, ** $p < 0.01$

Table 9. ANOVA results for factors Perceptual Load and Stimulus Relevance at each electrode array, for each of the two tasks at the 275 – 325 ms time window. All df = 1,15.

	Posterior				Anterior			
	Non-spatial task		Spatial task		Non-spatial task		Spatial task	
Source	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Perc. Load	6.38*	0.023	9.09**	0.009	11.94**	0.004	2.68	0.123
Stim. Rel.	29.85**	<0.001	7.56*	0.015	29.18**	<0.001	41.61**	<0.001
Perc. Load x Stim. Rel.	5.08*	0.040	36.18**	<0.001	1.81	0.199	7.04*	0.018

* $p < 0.05$, ** $p < 0.01$

Figure **31**. Grand average ERP waveforms from the non-spatial task, low perceptual load condition.

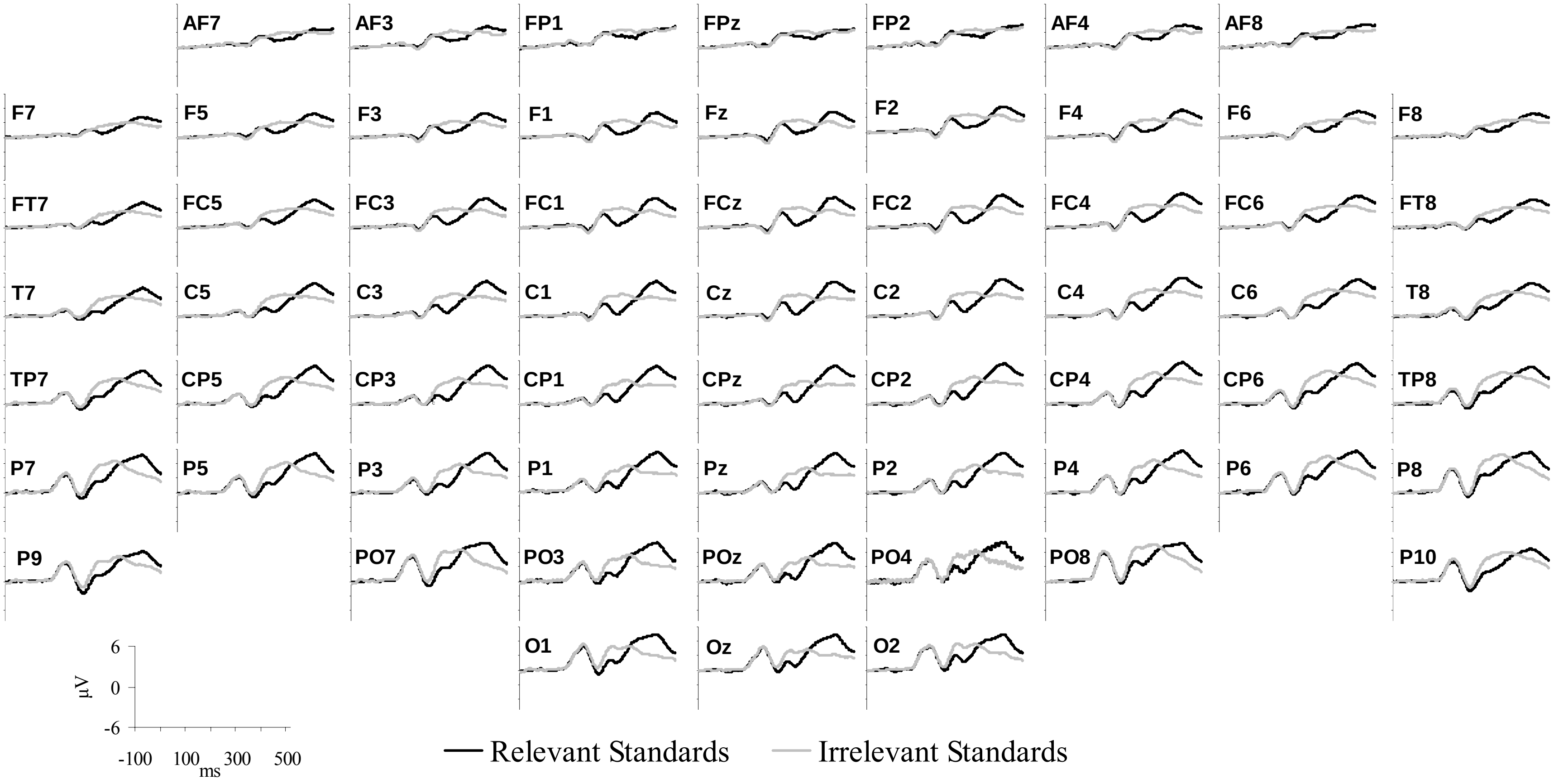


Figure **32**. Grand average ERP waveforms from the non-spatial task, high perceptual load condition.

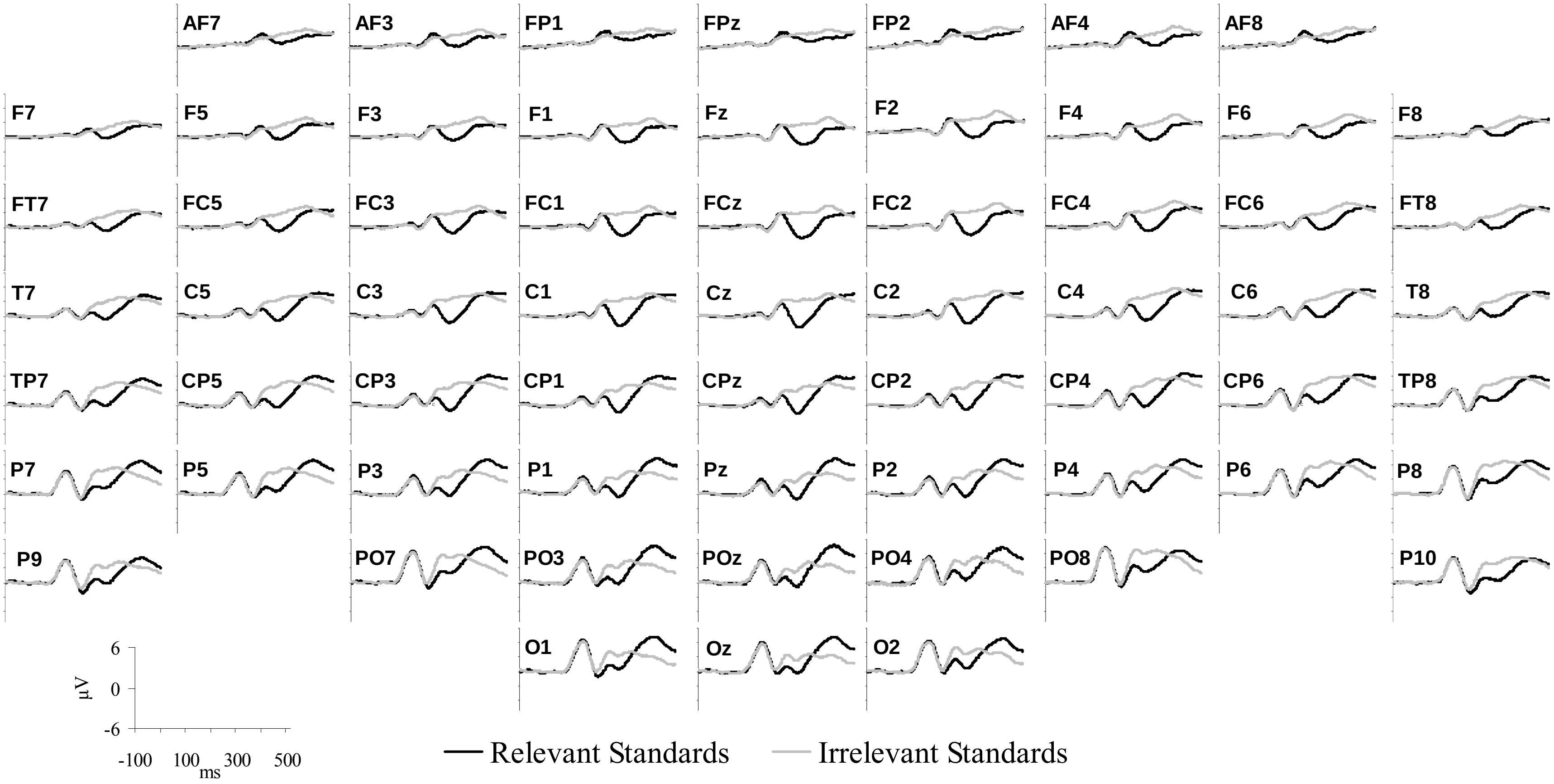


Figure 33. Grand average subtraction waveforms from the non-spatial task.

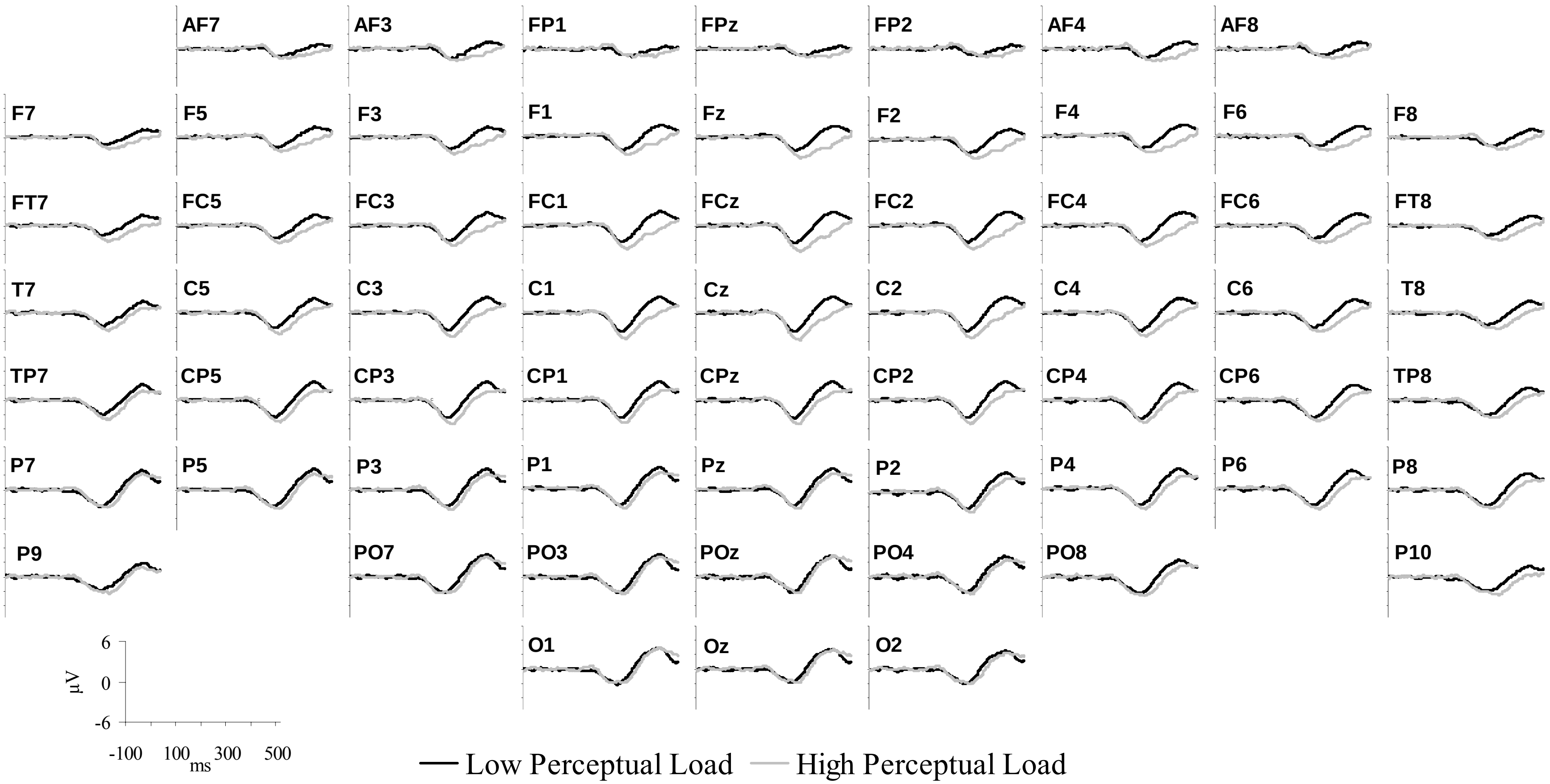


Figure **34**. Grand average ERP waveforms from the spatial task, low perceptual load condition.

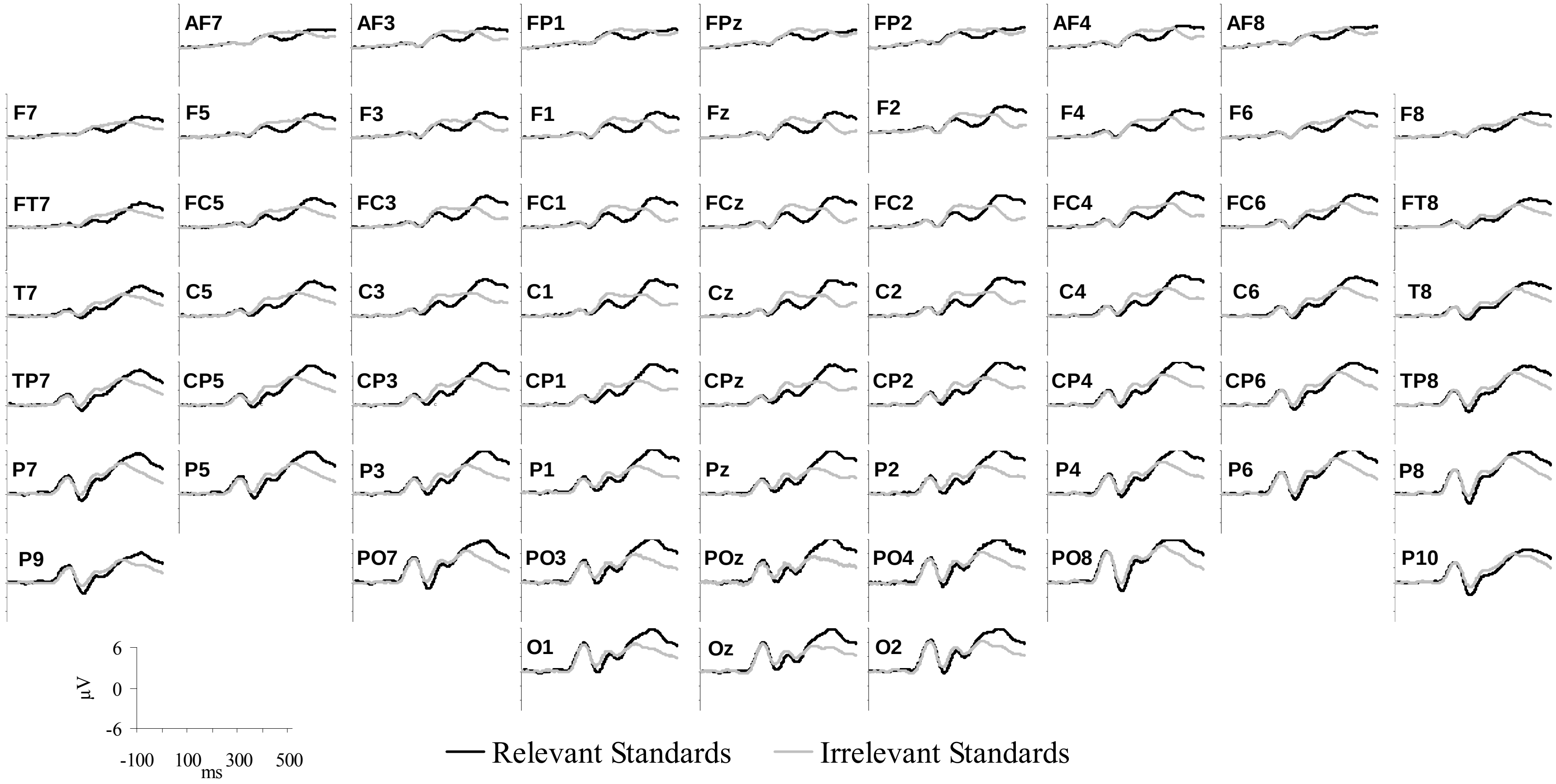


Figure 35. Grand average ERP waveforms from the spatial task, high perceptual load condition.

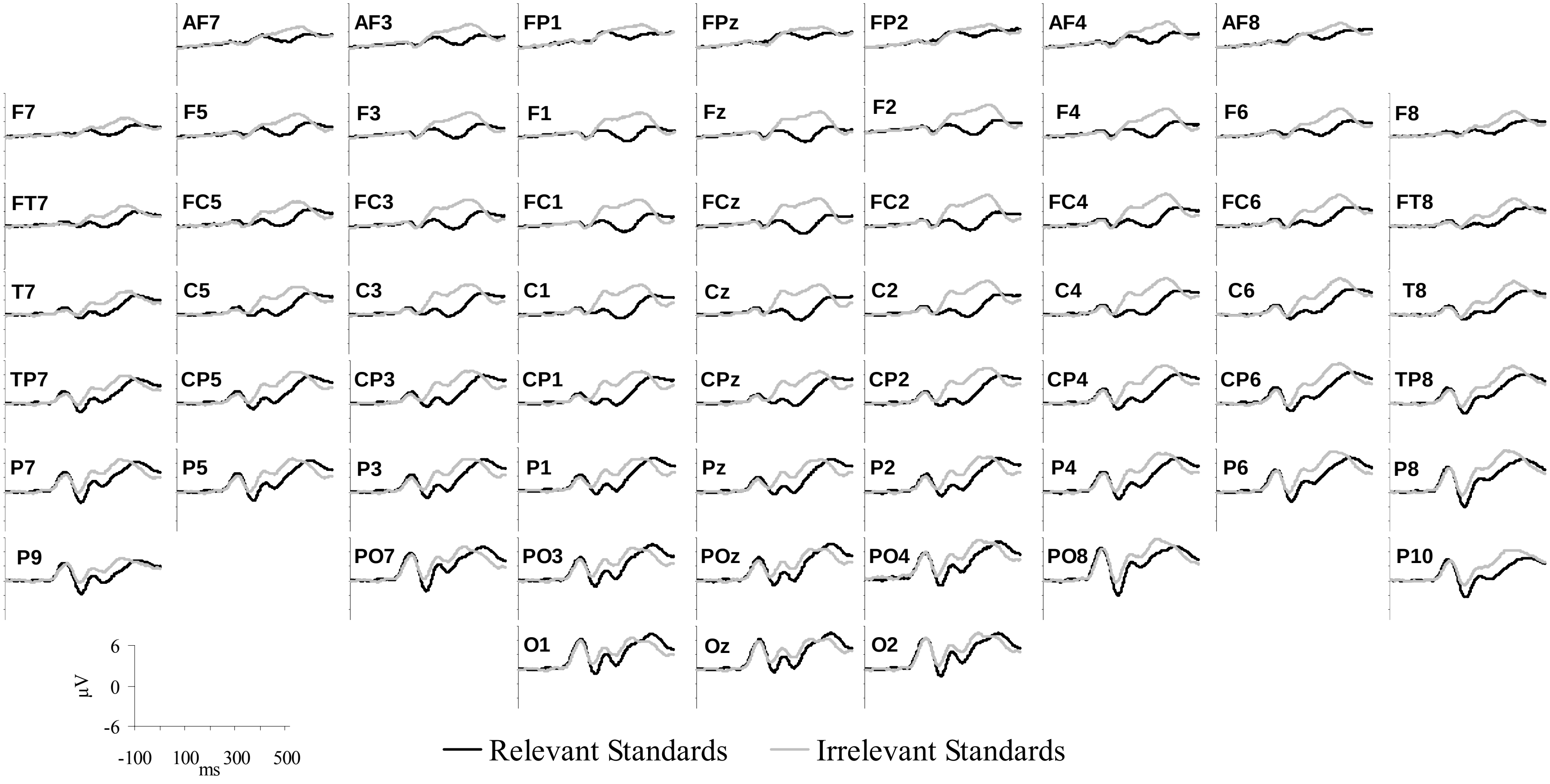


Figure **36**. Grand average subtraction waveforms from the spatial task.

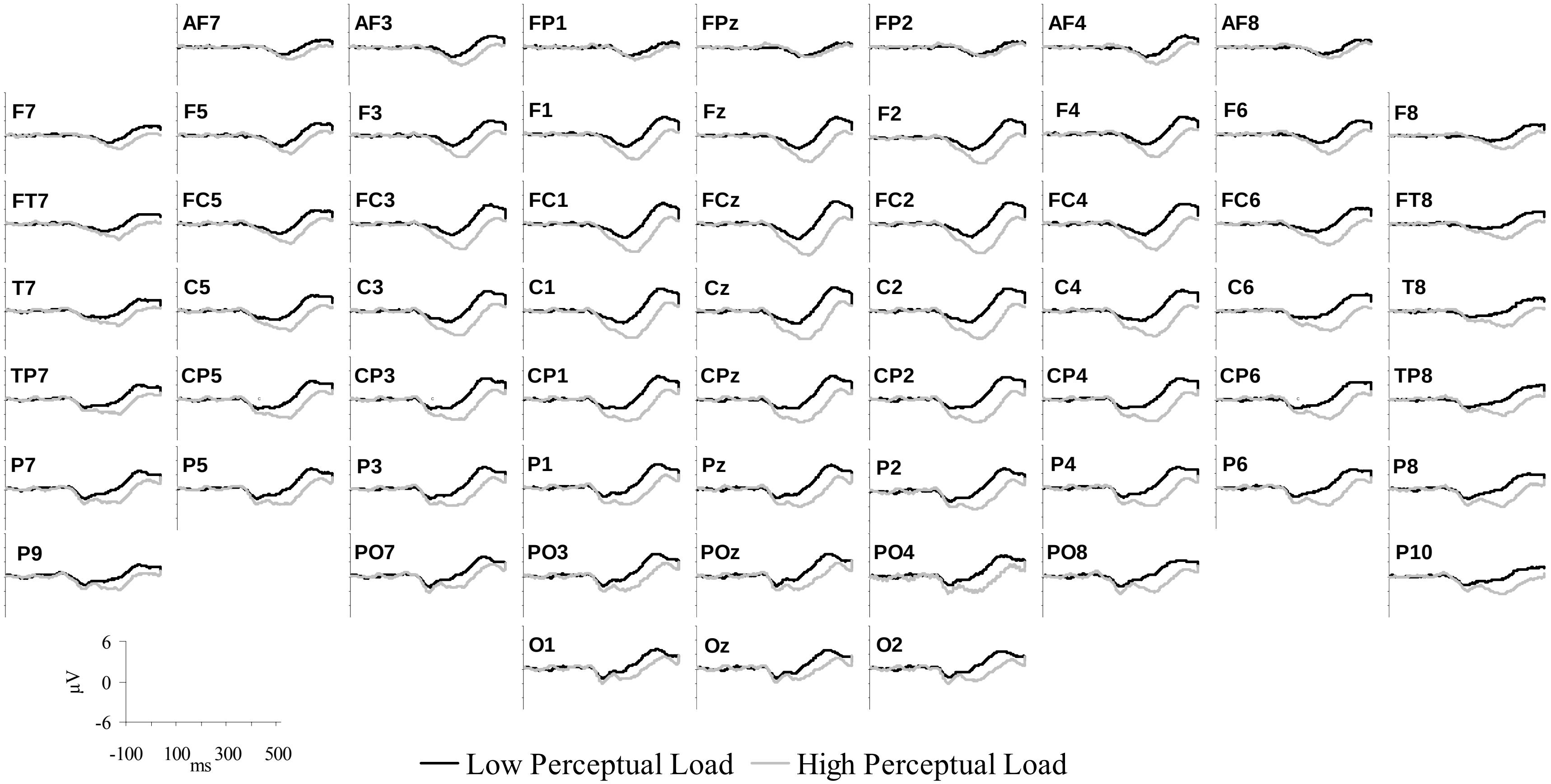


Figure 37. Grand average ERP waveforms from the non-spatial task, low perceptual load condition.

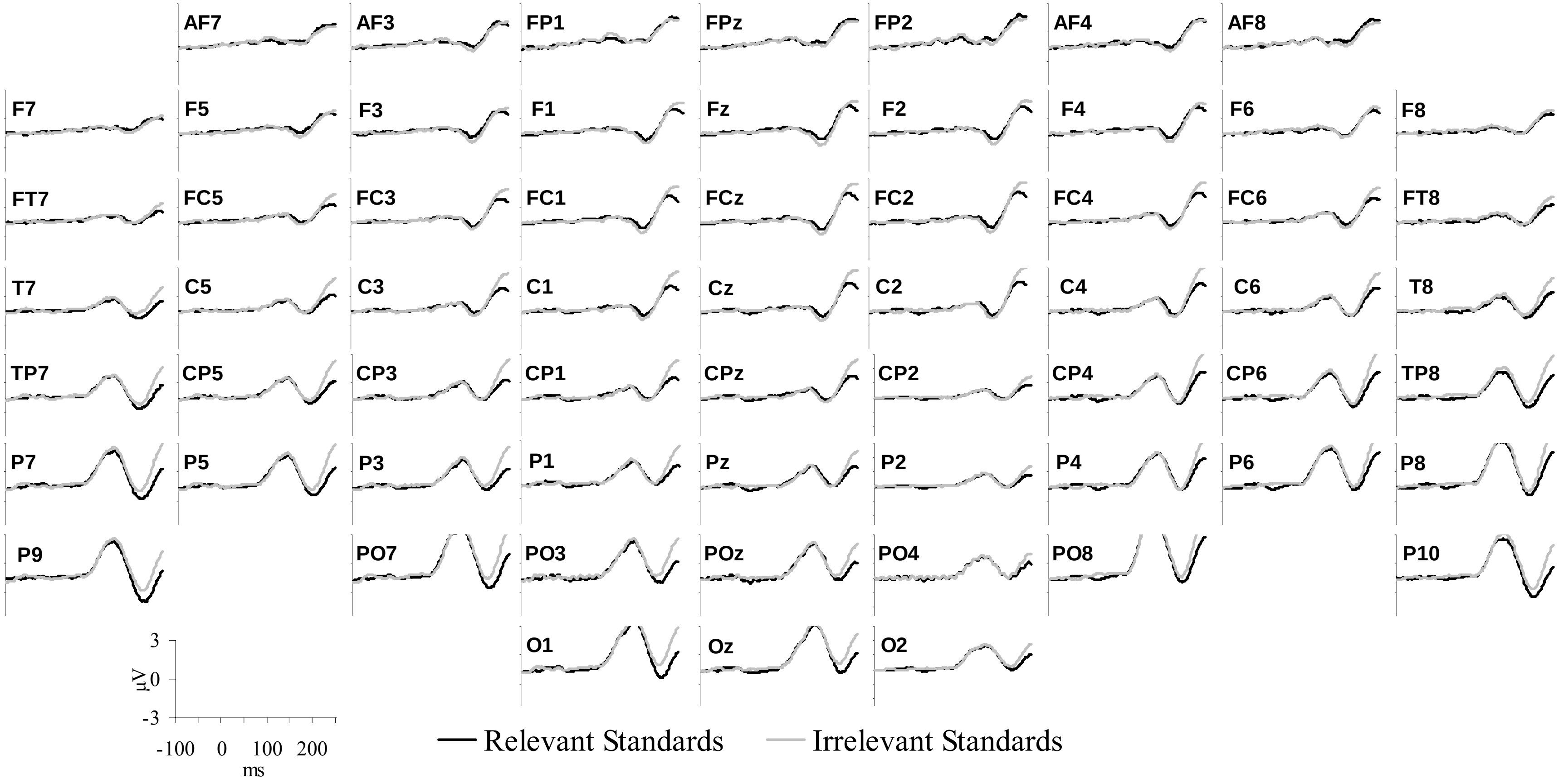


Figure **38**. Grand average ERP waveforms from the non-spatial task, high perceptual load condition.

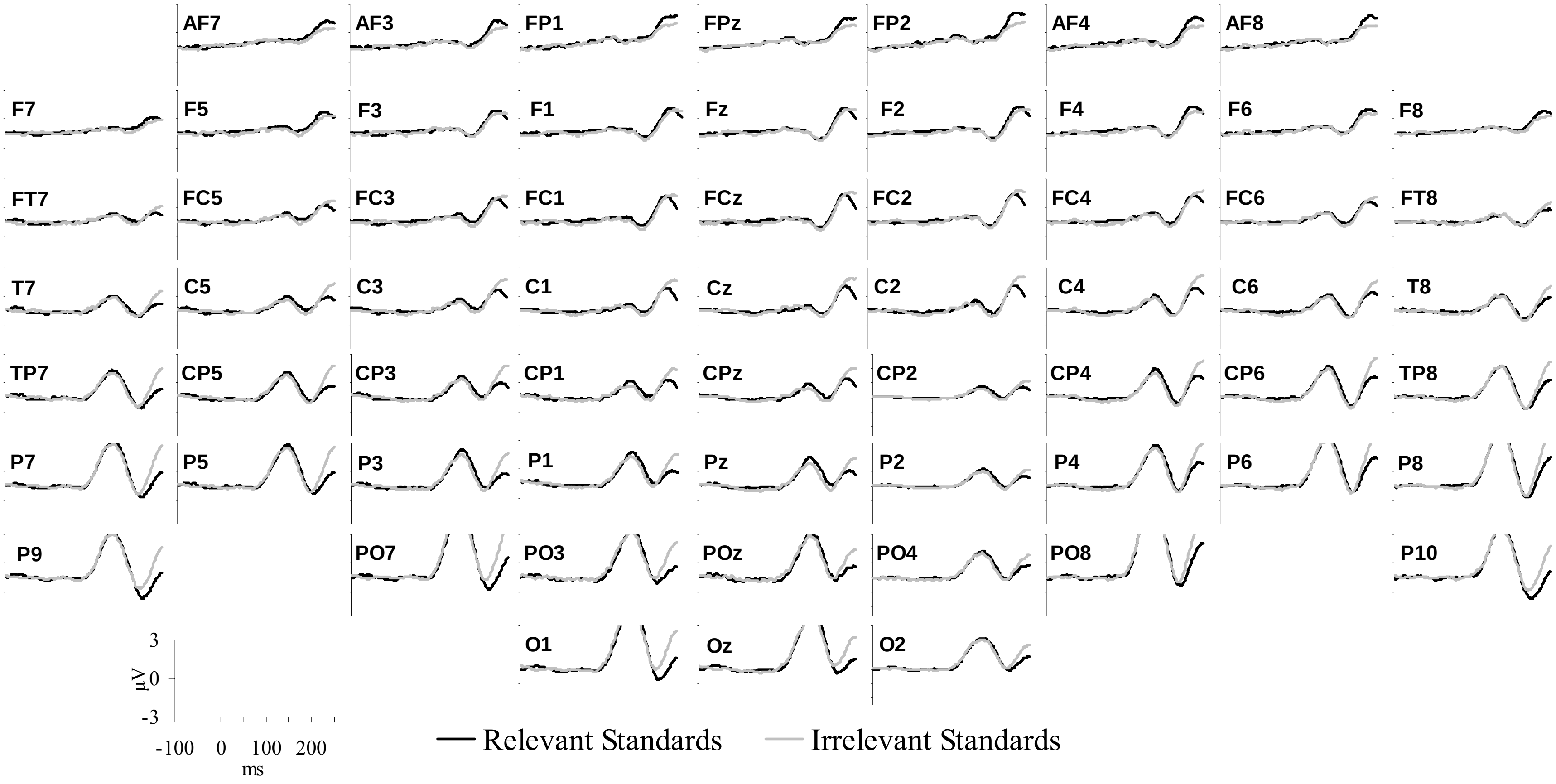


Figure **39**. Grand average ERP waveforms from the spatial task, low perceptual load condition.

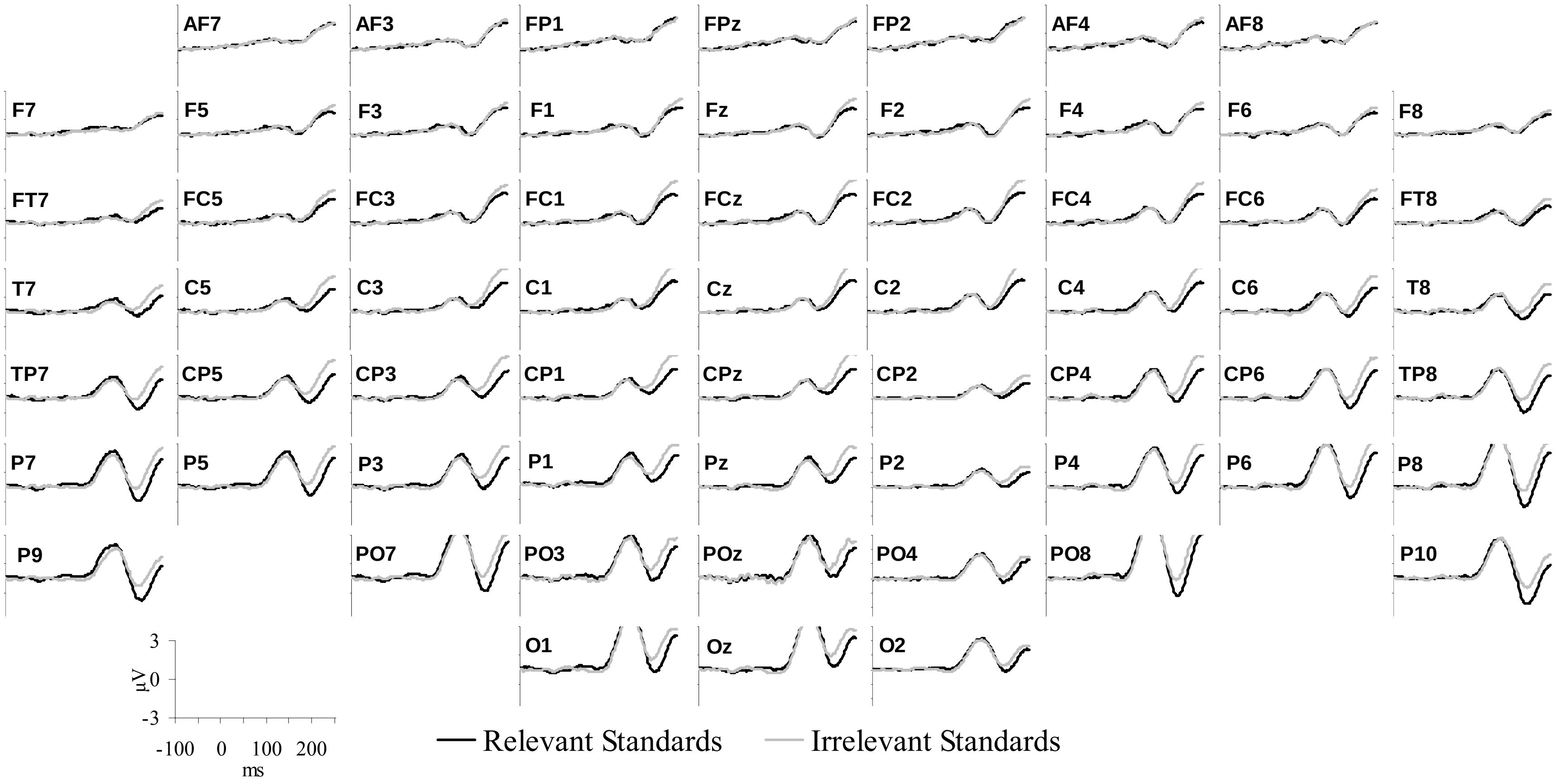
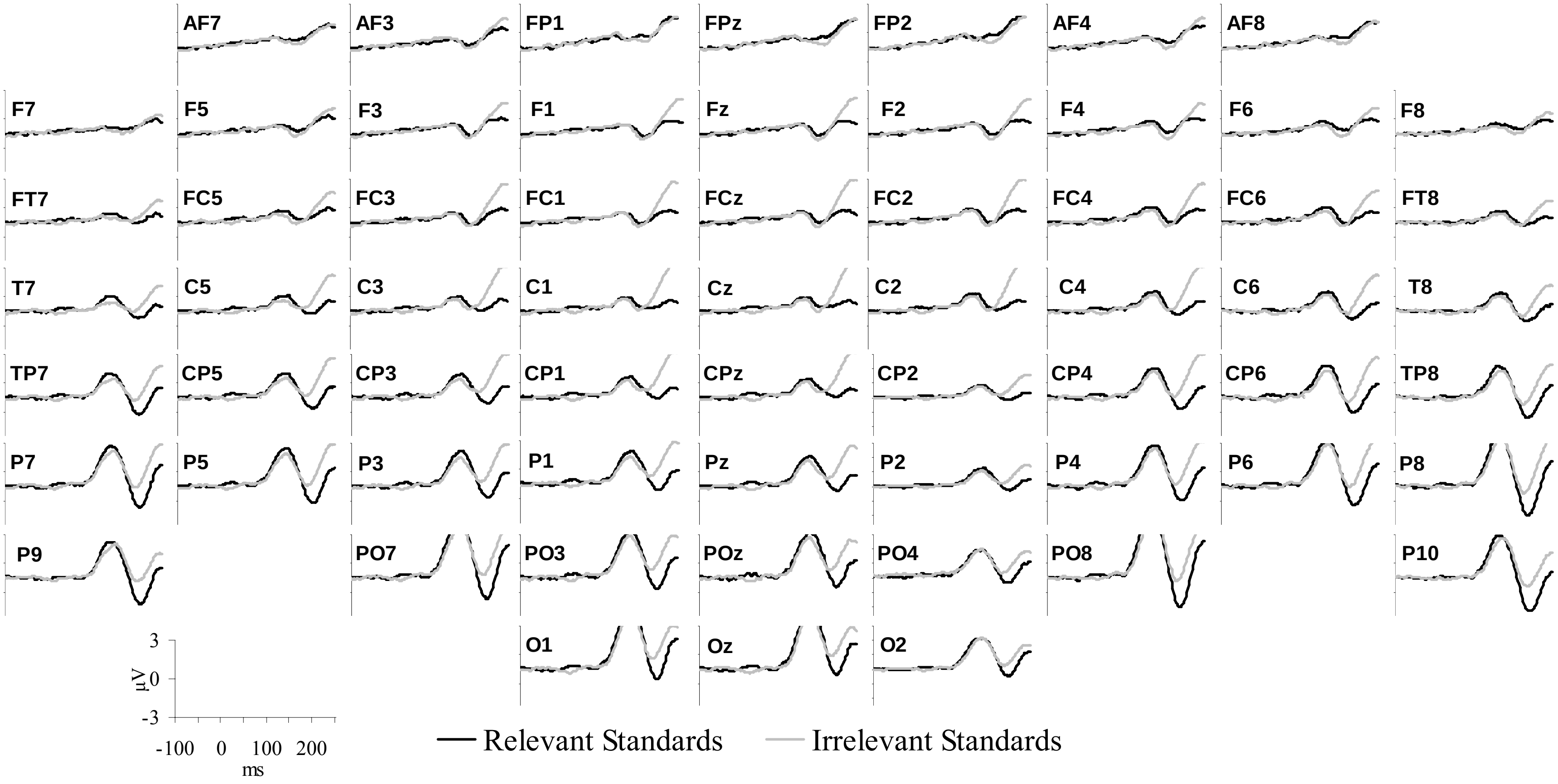


Figure **40**. Grand average ERP waveforms from the spatial task, high perceptual load condition.



Discussion

As expected, ERP waveforms were more negative in response to stimuli in the relevant channel than to stimuli in the irrelevant channel in both the non-spatial and spatial tasks, at the predicted 50 ms temporal windows. The first window, 175 – 225 ms post-stimulus, captured differences in the magnitude of the N1, an ERP component that is typically enhanced in response to stimuli that appear in relevant locations compared with irrelevant locations. The second window, 275 – 325 ms, captured the magnitude of the selection negativity (SN)- the difference wave that is formed by subtracting the ERP elicited by irrelevant stimuli from that elicited by relevant stimuli. Like the N1 component we observed, the peak of the SN was at a latency similar to what has been previously reported. Also consistent with past findings, the SN and the attentional enhancement of the N1 component were observed at electrode sites covering medial and lateral parietal and occipital scalp (for reviews see Hillyard and Anllo-Vento, 1998) and to a lesser extent to other scalp locations.

Crucially, perceptual load affected the attentional enhancement of the N1 (i.e., the larger magnitude found in N1 elicited by relevant stimuli relative to irrelevant stimuli) at predicted electrode sites when a spatial attribute defined stimulus channel. These findings were as predicted, and we interpret them as evidence in favor of perceptual load theory as described by Lavie (Lavie, 1995, 2005; Lavie & Cox, 1997; Lavie et al., 2004; Lavie & Tsal, 1994), who contends that the degree to which perceptual routines are loaded by relevant perceptual information is the major determinant of the amount of attentional processing that is brought to bear on irrelevant information. These results are consistent with Handy and Mangun (2000), who also reported a significant effect of perceptual load on the attentional enhancement of the N1. By contrast, perceptual load did not affect attentional modulations of ERPs at frontal scalp.

We supported perceptual load theory by employing a paradigm different from what has been used previously and obtaining results consistent with its predictions. We also found evidence that the theory may accurately describe non-spatial attention as well since in the non-spatial task SN amplitude was significantly larger under high perceptual load than it was under low load.

Even though the majority of evidence supporting this theory comes from the reliable finding that increasing perceptual load reduces the amount of interference from irrelevant, incompatible stimuli while increasing higher cognitive demands such as working memory does not do so, it remains possible that our manipulation of target/standard similarity either loaded higher cognitive demands and/or affected nonspecific aspects of task difficulty, rather than differentially loading perceptual routines as intended. However, this is highly unlikely to be the case in either task because of the dissociation between the significant ERP effects that we predicted to occur at posterior electrode sites and the absence of such effects at an analogous set of anterior sites. This dissociation will now be discussed. This will be followed by discussions of the dissociation between the N1 results in the two tasks, and of the implications of the current study for selective attention research.

Dissociation between posterior and anterior ERP findings

Although the fact that, in both tasks, perceptual load had a significant effect on RT, Hit and False Alarm rates, suggesting that our manipulation of perceptual load was successful (Theeuwes et al., 2004) and, when considered in the context of the ERP results just discussed, not due simply to task difficulty, it remains possible that we did not manipulate perceptual load *per se*. Even though we manipulated a perceptual aspect of the stimulus (discriminability), it could be the case that in doing so we differentially loaded higher cognitive processes instead of, or in addition to, perceptual load. For example, given that subjects were presumably required in the high load conditions to hold a more detailed representation of the standard stimulus in working memory, it is possible that there was more of a load on working memory operations in this condition when compared with the low load condition.

However, if this were the case, perceptual load modulations of the attentional ERP effects should have also, and to a larger extent, been evident at frontal electrode sites (Ruchkin, Johnson, Canoune, & Ritter, 1990). But as reported above, perceptual load did not modulate ERP activity during the epoch of the SN at more at frontal sites in the non-spatial task, nor did it modulate these sites during the epoch of the N1 (and N1 enhancement) in the spatial task.

Furthermore, Ruchkin et al. (1990) found that the amount of visual-spatial information that needed to be held in working memory affected ERP amplitude at much later temporal windows (> 1000 ms) than the windows analyzed in the current study. Ruchkin et al. (1990) did find that visual-spatial stimuli elicited a negative component in the general temporal range of our windows, the N220, that was larger in response to visual-spatial stimuli than to verbal stimuli but they found no modulation of working memory load at posterior electrode sites similar to the ones analyzed in the current study (i.e., parietal/occipital medial and lateral sites). Since we did not use a typical working memory paradigm such as the one used by Ruchkin and collegues, it was impossible to obtain ERPs for the time interval during which subjects were required to actively retain information (i.e., to use their working memory). It is therefore difficult to predict when any possible ERP modulations by working memory may be evident. Even with this difficulty regarding the timing of possible effects, it is probable that the locations of these effects would be frontally maximal (Ruchkin et al., 1990), given the abundance of evidence that working memory operations are mediated by frontal cortex, notably prefrontal cortex (PFC) (Cohen et al., 1997; Smith & Jonides, 1997).

It is also possible that the modulation of attend – unattend ERP differences by perceptual load that was found in the current study occurred because attention was disproportionately captured by the irrelevant channel under low load conditions. This is possible because the deviants in these conditions differered more, and therefore likely more noticeably, from the standards than they did under high load conditions. These deviants could thus have acted as singletons, drawing attention toward the irrelevant channel (Folk & Remington, 1998). If this was in fact the case, it could result in the smaller difference that we found between ERPs elicited by relevant and irrelevant stimuli under low load conditions.

However, our pilot data render this explanation very unlikely. In a pilot study, we employed a second high load condition (in addition to the high load condition employed in the current study) wherein the standard and target stimuli were identical to those in the low load condition. Instead, perceptual load was manipulated by adding three non-target deviants to the relevant channel. Crucially, load increased the attentional ERP enhancements as it did in the current study. For this reason, and because it necessitated the addition of another condition to control for the fact that target probability was lower than it was in the low load condition, the second high load condition was removed from the protocol.

Furthermore, our FA rates suggest that the relevant standard stimuli, which were identical across load conditions, were more distracting to subjects than the irrelevant deviants. Specifically, the FA rates to relevant standard stimuli were considerably higher in the high load conditions than in the low load conditions while the FA rates to irrelevant deviant stimuli were less than 0.05% in both load conditions. These findings strongly suggest that the effects of perceptual load on attend – unattend ERP differences found in the current study were not due to disproportionate attention capture by irrelevant deviant stimuli in the low load condition.

Dissociation between ERP and behavioral findings

If the added difficulty imposed by increasing perceptual load was greater in the spatial task than it was in the non-spatial task, then any interaction in the ERP results along these lines, such as the differential increase in N1 attentional enhancement by perceptual load, could potentially be a simple result of this difficulty difference, and not due to differences in perceptual load. Therefore, the finding of the current study that supports perceptual load theory in the spatial domain, namely that N1 attentional enhancement increases with perceptual load in the spatial but not in the non-spatial task, could be alternatively explained if the added difficulty imposed by the high perceptual load condition was greater in the spatial task than in the non-spatial task. However, the fact that perceptual load affected all three behavioral measures similarly across tasks renders this explanation extremely unlikely.

The behavioral measures of reaction time (RT), Hit rate, and False Alarm rate, either in isolation or combination, are widely cited as reliable measures of difficulty in cognitive / perceptual tasks. In the current study in particular, the rate of false alarms (FAs) made in response to relevant standards is arguably an indication of how difficult it was for subjects to discriminate targets from standards in the attended channel. The rate of correct responses to targets (i.e., Hits) and how fast subjects respond to the targets (i.e., RT) are also a valid measure of task difficulty. RT, Hit rate, and the FA rate to relevant standard stimuli all indicated that the added difficulty in the high perceptual load condition relative to the low load condition was the same in the non-spatial and spatial tasks (see Figures 2-4), demonstrated statistically by a lack of interaction between Perceptual Load and Task in any of the three behavioral measures (all *F*'s < 1).

When considered in contrast to the significant interaction between Perceptual Load and Stimulus Relevance observed in the spatial, but not non-spatial task at the latency of the N1 component, this represents a dissociation. That is, the critical ERP effect (attentional N1 enhancement) was not concomitant with effects involving any of the three behavioral measures reported above. This was not the case with the SN, which was affected by perceptual load in both tasks.

Implications for selective attention research

There are three primary implications of the current results. First, they support generally perceptual load theory as proposed by Lavie and Tsal (1994) in that they demonstrate perceptual load modulations of a putative spatial attention-related ERP effect. In doing so, they add to the existing support for the perceptual load theory found in the imaging and electrophysiological literature. The studies that comprise this body of literature are especially valuable because they measure directly the brain activity in response to attentional manipulations rather than inferring the operation of such brain processes from behavioral data alone.

Second, the results demonstrate that perceptual load may play a significant role in selection when relevant and irrelevant stimuli occupy the same physical location and are not present simultaneously. This is important because it suggests that perceptual load can have a tonically maintained effect on visual selection processes. That is, load was manipulated by varying the displacement of a feature of the target stimulus which made it more or less discernable from the standard and therefore the ERP effects we investigated were elicited by standard stimuli that were identical across load conditions. Given that the targets were randomly presented with a probability of only 10%, perceptual load was likely exerting an effect on selection processes when it was temporally far-removed from the presentation of the actual stimulus that varied across perceptual load conditions (i.e., the target). This is in stark contrast to interference studies, wherein the relevant stimuli presumably occupy attention at the time of the presentation of the irrelevant stimulus.

The third primary implication is that the results from the non-spatial task speak to the question of whether, or to what degree, the theory extends to non-spatial attentional processing. To the best of our knowledge, in all of the existing studies that manipulate perceptual load, subjects monitor a circumscribed spatial area for targets. Behavioral, as well as blood flow (rCBF), studies typically use a visual search / interference paradigm wherein relevant and irrelevant stimuli appear in predetermined spatial locations and in ERP studies spatial cuing paradigms are typically used (e.g., Handy & Mangun, 2000). Furthermore, in the behavioral and rCBF studies, the relevant information appears at fixation while the irrelevant information appears parafoveally, sometimes substantially so (e.g.,. up to 36 degrees of visual angle in Rees et al. (2001)).

In all of these studies then, subjects preferentially attend to a specific spatial location and stimuli that appear within it while attempting to ignore stimuli that appear in a spatially distinct location. In contrast, the current study included a task in which subjects monitored only one location, and instead preferentially attended stimuli that possessed a certain non-spatial attribute (color). In this task, enhancement of the N1 due to attention was not significantly affected by Perceptual Load, as it was in the spatial task. The absence of this effect was expected since non-spatial selection is associated with ERP effects that occur later in time than spatial effects, and are often not present at the N1 (Baas, Kenemans, & Mangun, 2002). As such, the latency of the N1 peak could simply have preceded any possible non-spatial attention effects. However, this explanation is contradicted by the fact that Stimulus Relevance significantly modulated N1 amplitude in general in the non-spatial task. This result is therefore somewhat equivocal.

At the later time window (275 – 325 ms), however, perceptual load significantly modulated SN amplitude in the non-spatial task. Thus, there was more of a difference in attentional processing afforded relevant and irrelevant information under conditions of high perceptual load, a finding suggesting that perceptual load may be an important factor in determining the efficiency of *non*-spatial attention.

The results of the current study should also be viewed in the context of a similar selective attention study conducted in our laboratory (described above) in which auditory stimuli were used. In that study, subjects also performed a two-channel selective attention ‘go no-go’ task and, although perceptual load was manipulated in a different fashion than it was in the current study, we nevertheless operationalized it according to the definition proposed by Lavie (2005). As in the current study, perceptual load affected behavioral measures but unlike the current study it did not modulate the attentional ERP effects (i.e., the Nd) that we observed. The significant effect of load on attentional ERP effects in the current study constrains the alternative explanations of the results from our auditory study (i.e., reasons for the null finding other than the inaccuracy of the perceptual load hypothesis) in two important ways.

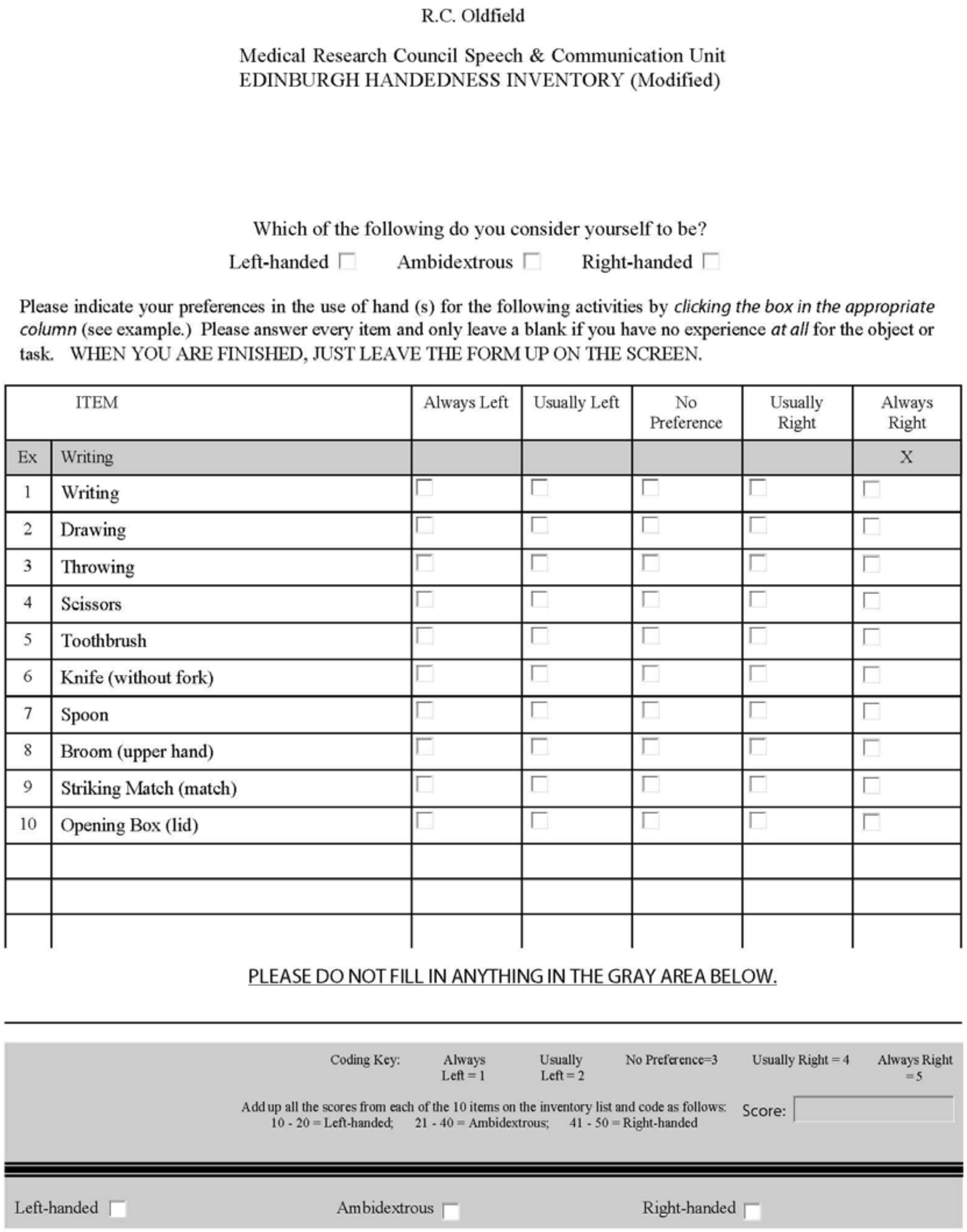
First, it validates the use of the two-channel selection paradigm as a means to test the perceptual load hypothesis. Second, it eliminates the possibility that perceptual load influences selection only when both relevant and irrelevant stimuli are presented simultaneously. In doing so, the current study constrains the interpretation of the null ERP effects in our auditory study, making it more likely that perceptual load theory is valid, but only in the visual modality.

Conclusions

The current study provides evidence in favor of the hypothesis that the loading of perceptual routines affects the difference in attentional processing brought to bear on relevant and irrelevant stimuli. It provides this evidence by demonstrating putative selective attention-related ERP effects, namely an enhancement of an early negative component (the N1) and the difference waveform referred to as the selection negativity (SN) that results from subtracting ERP elicited by relevant stimuli from the ERP elicited by irrelevant stimuli, are affected by perceptual load. Both the SN and the modulation by Stimulus Relevance of the N1 were increased when perceptual load was increased in a spatial task, whereas only the SN was affected by load in the non-spatial task. This is the pattern of results that would be expected if perceptual load theory accurately described not just spatial selection in an interference paradigm, where subjects must select a relevant stimulus and exclude other irrelevant and potentially interfering stimuli, but also in a two-channel selective attention task, where subjects are only exposed to one stimulus at a time. This is important because it suggests that the changes in attentional processing caused by perceptual load can be tonically maintained across trials, and that load may not exert its effect by reducing response interference, as the current perceptual load framework stipulates. It further shows that perceptual load has a similar effect when all stimuli occupy the same physical space, and the stimuli to-be-attended, that is, the stimuli that are relevant for the task, are discriminated based on a non-spatial feature.

In sum, the current results support perceptual load theory, but also lend support for the notion that it accurately describes attention processing in a different task (i.e., two-channel, go no-go) and domain (i.e., non-spatial processing) that have been as yet unexplored. Furthermore, when taken together with the results from a similar study conducted in our laboratory, the current results suggest that perceptual load is an important factor in determining selection processes in the visual, but not the auditory modality.

Appendix A.



R.C. Oldfield

Medical Research Council Speech & Communication Unit
EDINBURGH HANDEDNESS INVENTORY (Modified)

Which of the following do you consider yourself to be?

Left-handed ☐ Ambidextrous ☐ Right-handed ☐

Please indicate your preferences in the use of hand (s) for the following activities by *clicking the box in the appropriate column* (see example.) Please answer every item and only leave a blank if you have no experience *at all* for the object or task. WHEN YOU ARE FINISHED, JUST LEAVE THE FORM UP ON THE SCREEN.

ITEM		Always Left	Usually Left	No Preference	Usually Right	Always Right
Ex	Writing					X
1	Writing	☐	☐	☐	☐	☐
2	Drawing	☐	☐	☐	☐	☐
3	Throwing	☐	☐	☐	☐	☐
4	Scissors	☐	☐	☐	☐	☐
5	Toothbrush	☐	☐	☐	☐	☐
6	Knife (without fork)	☐	☐	☐	☐	☐
7	Spoon	☐	☐	☐	☐	☐
8	Broom (upper hand)	☐	☐	☐	☐	☐
9	Striking Match (match)	☐	☐	☐	☐	☐
10	Opening Box (lid)	☐	☐	☐	☐	☐

PLEASE DO NOT FILL IN ANYTHING IN THE GRAY AREA BELOW.

Coding Key: Always Left = 1 Usually Left = 2 No Preference=3 Usually Right = 4 Always Right = 5

Add up all the scores from each of the 10 items on the inventory list and code as follows:
10 - 20 = Left-handed; 21 - 40 = Ambidextrous; 41 - 50 = Right-handed

Score: ☐

Left-handed ☐ Ambidextrous ☐ Right-handed ☐

Appendix B.

Instructions for NON-spatial task - Attend BLUE

“In the following block of trials, you will see a series of symbols presented, one at a time, in the center of the computer screen (sample stimuli displayed on screen). Half of the symbols will be red, and half will be blue.

“In this block, I want you to pay attention to the BLUE symbols. 80% of the time, the blue symbol will look like this (standard blue symbol displayed on computer screen) - this is called the “standard stimulus” because it appears most often. But 20% of the time it will look like this (deviant blue symbol displayed on screen) - this is called the “deviant” stimulus because it appears more rarely.

**** If subject has already been exposed to the other load condition, read the following instructions. Otherwise, skip this section ****

“You’ll notice that the standard stimulus is the same as before, but the deviant stimulus is different.

“Your task is to press the #2 button on your response pad AS QUICKLY AS YOU CAN whenever you see the deviant BLUE symbol. Since you are only pressing the button for deviant BLUE symbols, you should do your best to ignore all the RED symbols.

“Keep in mind that the stimuli are delivered randomly, and the block will last approximately 6 minutes. Also remember to keep your eyes on the fixation cross. It may be tempting to move your eyes, but please refrain from doing so. Try to keep blinking to a minimum, but blink when you feel you must.”

Appendix B cont.

Instructions for NON-spatial task - Attend RED

"In the following block of trials, you will see a series of symbols presented, one at a time, in the center of the computer screen (sample stimuli displayed on screen). Half of the symbols will be BLUE, and half will be RED.

"In this block, I want you to pay attention to the RED symbols. 80% of the time, the RED symbol will look like this (standard RED symbol displayed on computer screen) - this is called the "standard stimulus" because it appears most often. But 20% of the time it will look like this (deviant RED symbol displayed on screen) - this is called the "deviant" stimulus because it appears more rarely.

**** If subject has already been exposed to the other load condition, read the following instructions. Otherwise, skip this section ****

"You'll notice that the standard stimulus is the same as before, but the deviant stimulus is different.

"Your task is to press the #2 button on your response pad AS QUICKLY AS YOU CAN whenever you see the deviant RED symbol. Since you are only pressing the button for deviant RED symbols, you should do your best to ignore all the BLUE symbols.

"Keep in mind that the stimuli are delivered randomly, and the block will last approximately 6 minutes. Also remember to keep your eyes on the fixation cross. It may be tempting to move your eyes, but please refrain from doing so. Try to keep blinking to a minimum, but blink when you feel you must."

Appendix C.

Instructions for SPATIAL task - Attend LEFT

"In the following block of trials, you will see a series of symbols presented, one at a time, in the center of the computer screen (sample stimuli displayed on screen). Half of the symbols will be slightly to the RIGHT of the fixation spot, and half will be slightly to the LEFT.

"In this block, I want you to pay attention to the symbols on the LEFT. 80% of the time, the symbol on the LEFT will look like this (standard LEFT symbol displayed on computer screen) - this is called the "standard stimulus" because it appears most often. But 20% of the time it will look like this (deviant LEFT symbol displayed on screen) - this is called the "deviant" stimulus because it appears more rarely.

**** If subject has already been exposed to the other Perceptual load condition - read the following instructions. Otherwise, skip this section ****

"You'll notice that the standard stimulus is the same as before, but the deviant stimulus is different.

"Your task is to press the #2 button on your response pad AS QUICKLY AS YOU CAN whenever you see the deviant symbol on the LEFT. Since you are only pressing the button for deviant symbols on the LEFT, you should do your best to ignore all the symbols on the RIGHT.

"Keep in mind that the stimuli are delivered randomly, and the block will last approximately 6 minutes. Also remember to keep your eyes on the fixation cross. It may be tempting to move your eyes, but please refrain from doing so. Try to keep blinking to a minimum, but blink when you feel you must."

Appendix C cont.

Instructions for SPATIAL task - Attend RIGHT

"In the following block of trials, you will see a series of symbols presented, one at a time, in the center of the computer screen (sample stimuli displayed on screen). Half of the symbols will be slightly to the LEFT of the fixation spot, and half will be slightly to the RIGHT.

"In this block, I want you to pay attention to the symbols on the RIGHT. 80% of the time, the symbol on the RIGHT will look like this (standard RIGHT symbol displayed on computer screen) - this is called the "standard stimulus" because it appears most often. But 20% of the time it will look like this (deviant RIGHT symbol displayed on screen) - this is called the "deviant" stimulus because it appears more rarely.

**** If subject has already been exposed to the other Perceptual load condition - read the following instructions. Otherwise, skip this section ****

"You'll notice that the standard stimulus is the same as before, but the deviant stimulus is different.

"Your task is to press the #2 button on your response pad AS QUICKLY AS YOU CAN whenever you see the deviant symbol on the RIGHT. Since you are only pressing the button for deviant symbols on the RIGHT, you should do your best to ignore all the symbols on the LEFT.

"Keep in mind that the stimuli are delivered randomly, and the block will last approximately 6 minutes. Also remember to keep your eyes on the fixation cross. It may be tempting to move your eyes, but please refrain from doing so. Try to keep blinking to a minimum, but blink when you feel you must."

Appendix D.

On-screen instructions shown to subjects prior to the low perceptual load condition, non-spatial task. (Attend-Red condition is shown below.

“ATTEND **<u>RED</u>**”

<u>ATTEND</u> IGNORE

40 % Standard >

10 % Deviant >

(red) *(blue)*

Appendix E.

On-screen instructions shown to subjects prior to the high perceptual load condition, non-spatial task. (Attend-Blue condition is shown below.)

“ATTEND **BLUE**”

ATTEND IGNORE

40 % Standard >

10 % Deviant >

(blue) (red)

Appendix F.

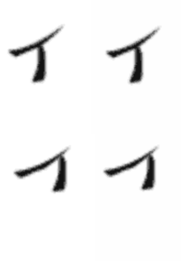
On-screen instructions shown to subjects prior to the low perceptual load condition, spatial task. (Attend-Left condition is shown below.)

“ATTEND **<u>LEFT</u>**”

<u>ATTEND</u> IGNORE

40 % Standard >

10 % Deviant >



Appendix G.

On-screen instructions shown to subjects prior to the high perceptual load condition, spatial task. (Attend-Right condition is shown below.)

“ATTEND **RIGHT**”

IGNORE **ATTEND**

<Standard 40 %

<Deviant 10 %

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Autobiographical Statement

Weighing on my mind throughout this project was the fact that my father, Karl Barnhardt, would not be able to share in the joy and excitement of its completion.