Published in final edited form as:

Psychophysiology. 2015 September ; 52(9): 1140–1148. doi:10.1111/psyp.12446.

Multitasking: Effects of processing multiple auditory feature patterns

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Abstract

ERPs and behavioral responses were measured to assess how task-irrelevant sounds interact with task processing demands and affect the ability to monitor and track multiple sound events. Participants listened to four-tone sequential frequency patterns, and responded to frequency pattern deviants (reversals of the pattern). Irrelevant tone feature patterns (duration and intensity) and respective pattern deviants were presented together with frequency patterns and frequency pattern deviants in separate conditions. Responses to task-relevant and task-irrelevant feature pattern deviants were used to test processing demands for irrelevant sound input. Behavioral performance was significantly better when there were no distracting feature patterns. Errors primarily occurred in response to the to-be-ignored feature pattern deviants. Task-irrelevant elicitation of ERP components was consistent with the error analysis, indicating a level of processing for the irrelevant features. Task-relevant elicitation of ERP components was consistent with behavioral performance, demonstrating a “cost” of performance when there were two feature patterns presented simultaneously. These results provide evidence that the brain tracked the irrelevant duration and intensity feature patterns, affecting behavioral performance. Overall, our results demonstrate that irrelevant informational streams are processed at a cost, which may be considered a type of multitasking that is an ongoing, automatic processing of task-irrelevant sensory events.

Descriptors

Cognition; EEG; Normal volunteers; Auditory processes; Attention

In this age of fast-paced technology, where instantaneous gratification is possible at the click of a button, people have come to expect more of themselves and those around them, struggling to accomplish more in less time. Multitasking, or attempting to multitask, has become almost second nature (e.g., commuters talk on cell phones while driving and people text while walking). Although technology has undergone explosive growth in capability, humans still experience the same limitations of attentional capacity.

Attention limits the “sea” of sensory input, enabling individuals to select out and focus on high-priority stimuli, rather than becoming overloaded by the onslaught of the daily stimulation. Because people possess a limited amount of attentional resources, it is difficult

to attend to multiple stimuli in the environment at once (Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1984). The extent to which this is true has been disputed. William James famously asserted that we can only attend to one thing at a time (James, 1890), an idea that was echoed in Broadbent's filter theory (Broadbent, 1958). Those who have suggested that multitasking is possible generally assert that the ability relies on automatic processes (Shiffrin & Schneider, 1984; Spelke, Hirst, & Neisser, 1976) and is dependent upon task load (Lavie, 2005). For example, we can drive and talk at the same time when the task of driving has become automatized. Consider driving, however, when traffic conditions suddenly become challenging. Midsentence you stop talking to attend to the road, likely without even noticing that you stopped talking. This indicates that multitasking is not possible when one of the tasks requires full attention. That is, when the "automatic" task needs additional resources, the ability to multitask diminishes with increasing cognitive load. However, for less practiced cognitive tasks, we do not understand how much of the unattended information is processed and available for use by attentional systems when needed (Sussman, Bregman, & Lee, 2014).

Although people often appear as though they can multitask effectively—students seem perfectly capable of answering questions, typing lecture notes, checking e-mails, and sending text messages at once—multitasking may interfere with task performance altogether. Strayer, Drews, and Crouch (2006), for example, found that cell phone conversations hindered driving performance to the extent that cell phone users posed similar safety hazards as drunk drivers. Assuming individuals can focus on only one task at a time, the explanation for this multitasking ability is that they are actually shifting attention rapidly back and forth between tasks, which only gives the appearance of multitasking (Spelke et al., 1976). That is, the "cost" of attention, a measurable decrease in performance level, may be due to dividing between active (relevant) tasks.

But how, then, while preoccupied with a single task, are individuals able to immediately respond to previously unattended stimuli? The current study tests the idea of multitasking but includes task processing of both relevant and irrelevant auditory information, with the hypothesis that irrelevant information is maintained in organized, informational streams. Thus, this study tests the degree of processing for task-irrelevant sounds when attention is directed to a subset of the input to perform a task. We propose that, to be able to switch attention rapidly from one task to another, task-irrelevant sounds are structured at some level to allow monitoring of the background scene. The structured information stored in memory could provide the ability to rapidly switch attention among features of the background sounds. Thus, the overarching hypothesis of the current study is that the organizational structure is represented and maintained for task-irrelevant information. However, as attention is a limited resource, background processing may draw resources away from the main task. This may then have a resultant effect similar to a traditional multitasking paradigm (when two tasks are actively performed), in which a decrease in behavioral performance is observed on the main task. From this perspective, we can consider the background monitoring as a type of multitasking. Thus, we may expect a decrement in task performance, even when the multitasking involves performing one task and processing of task-irrelevant auditory input.

To begin to address this question, it is necessary to understand how the brain organizes and maintains representations of the background sounds. Sussman and others have established that the brain does not completely relegate unattended information to undifferentiated background noise (Fishman, Micheyl, & Steinschneider, 2012; Jones, Alford, Bridges, Tremblay, & Macken, 1999; Sussman, 2005; Sussman, Ritter, & Vaughan, 1998, 1999). For example, some level of stream segregation occurs even under high load task situations (Pannesse, Herrmann, & Sussman, 2014). Pannesse et al. showed that sound streams segregated by tone frequency were held in memory outside the focus of attention, even if the cognitive load may have reduced further processing of the distinct frequency streams. The efficiency of the segregation and maintenance of distinct auditory streams in memory is especially important, given the transient nature of auditory stimuli (Sussman, 2005). If unattended auditory signals are not unraveled immediately, there is no more opportunity to recapture and process the sounds: the physical input is gone. The only information that can be used to recapture the input is the neural trace of the sounds held in transient memory. Many studies have indicated that, no matter where attention is directed, some level of auditory processing occurs for unattended inputs (e.g., Broadbent, 1958; Cherry, 1953; Dalton & Hughes, 2014; Lange, 2005; Neisser, 1967; Pannesse et al., 2014; Parmentier, 2014; Schröger & Wolff, 1998; Sussman, 2005; Sussman et al., 1998, 1999). However, even if we agree that unattended sounds are processed at some level, the question of the extent to which this processing takes place is still an open and debated issue.

In the current study, we used auditory feature patterns (see Method for details) to analyze how the brain negotiates complex background stimuli while attending to a specific task. Feature patterns require higher levels of processing because temporal patterns of sound features (e.g., frequency, duration, intensity) have to be extracted from the tones that carry them. Thus, they were used here to demonstrate the extent to which the brain is able to detect sequential feature patterns for irrelevant tone features when a task is being performed with another tone feature. If background monitoring occurs at a level that allows automatic pattern detection, then the brain's response to embedded violations of the pattern will reveal this. Electroencephalogram was recorded while listeners responded to reversals of the frequency patterns (deviants). The brain's response to the pattern reversals in the task-irrelevant features (duration and intensity) was used to indicate if the irrelevant feature patterns were maintained in memory while performing a task in the spectral domain. Elicitation of the mismatch negativity (MMN) component of the ERPs was used to assess whether the pattern reversals of the task-irrelevant tone features were detected.

MMN is a good tool for the current investigation because it relies on functions involving auditory sensory memory, and can index unattended (automatic) sound processing while the listener performs a task. The MMN is generated within auditory cortices, and its elicitation is dependent upon open N-methyl-D-aspartate (NMDA) channels (Javitt, Steinschneider, Schroeder, & Arezzo, 1996). NMDA-mediated activity is associated with cellular mechanisms involved in memory processes (Compte, Brunel, Goldman-Rakic, & Wang, 2000; Kauer, Malenka, & Nicoll, 1988; Pulvirenti, 1992), suggesting a link between memory and MMN. Further, MMN provides an important dependent measure because it operates under both passive and active sound detection conditions, indexing automatic processes that are not task dependent.

Because MMN elicitation is dependent upon the neural representation of the repeating feature patterns (standard), results will provide insight into the structuring and storing of unattended acoustic information in memory (Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001; Sussman, 2007; Sussman, Chen, Sussman-Fort, & Dinces, 2013). That is, MMNs elicited in response to task-irrelevant feature patterns would provide evidence that they were stored in memory even when irrelevant to the task. This would indicate that structured information of unattended sounds was held in memory and could provide the ability to rapidly switch attention among features of the background sound.

In addition to MMN elicitation for both task-relevant and task-irrelevant feature patterns, the P3b component of ERPs was used as a task-relevant index of target detection. The P3b component is only elicited when subjects perform a task and thus reflects active task-related processes (Picton, 1992). Therefore, P3b should be elicited by target frequency patterns and not by irrelevant (nontarget) feature patterns.

Finally, behavioral responses (e.g., reaction time and hit rate) were used to provide a measure of the effects of irrelevant sound processing on task performance. Evidence to support our hypothesis would thus be found if behavioral performance was affected by processing pattern deviants of irrelevant tone features (e.g., longer reaction time), along with evidence of deviance detection for the task-irrelevant feature patterns (e.g., MMN elicitation).

Method

Participants

Eleven adults (7 males, 4 females; 10 right-handed), ranging in age from 21 to 36 years ($M = 28$, $SD = 6$) participated in the study. All participants passed a hearing screening (20 dB HL at 500, 1000, 2000, and 4000 Hz) and had no reported history of neurological disorders. The Internal Review Board of the Albert Einstein College of Medicine, where the study was conducted, approved the procedures. All participants gave written consent before participating and were paid for their participation.

Stimuli and Procedures

Two pure tones were created using Neuroscan Stimulation software (Compumedics Inc., Charlotte, NC; using Hanning window and 7.5 ms rise/fall times) and presented bilaterally through insert earphones (E-A-RTONE 3A, Indianapolis, IN) in three conditions (frequency alone, frequency-duration, and frequency-intensity). One tone had a frequency of 1047 Hz (denoted by an A for the lower tone) and the other tone had a frequency of 1175 Hz (denoted by a B for the higher tone).

In the frequency alone (FA) condition, the two different frequency tones (both 150 ms in duration) were presented in a four-tone sequential pattern (AABBAABB ...), with a 250-ms stimulus onset asynchrony (Figure 1A). Each tone had an intensity level of 70 dB peak SPL. Randomly, for 10% of the tones, the frequency pattern was reversed (BBAA). Participants were instructed to listen for the repeating four-tone melodic pattern and press the response

key as soon as they detected the reversal of the pattern. Thus, the button press occurred time-locked to the first B tone of the deviant pattern.

In the frequency-duration (FD) condition, half of the tones were 150 ms in duration (denoted by a C) and the other half were 50-ms duration (denoted by a D). Thus, there were two feature patterns, one in the frequency dimension (AABBAABB ...) and one in the temporal dimension (CCDDCCDD ...). The duration pattern was staggered with respect to the frequency pattern, such that they did not occur simultaneously in time (Figure 1B). Deviant patterns were the reversals of the standard feature patterns (e.g., BBAA and DDCC), which occurred randomly at a rate of 10% for each.

In the frequency-intensity (FI) condition, half the tones were 70 dB peak SPL (denoted by an E) and half were 60 dB peak SPL (denoted by an F). The duration of the tones were all 150 ms. Thus, there were two feature patterns, one in the frequency dimension (AABBAABB ...) and one in the intensity dimension (EEFFEEFF ...). The intensity feature pattern was staggered with respect to the frequency feature pattern, similarly as was done in the FD condition (Figure 1C). Deviant patterns were the reversals of the standard feature patterns (e.g., BBAA and FFEE), occurring randomly, 10% each.

The task for the FD and FI conditions was the same as for the FA condition: participants were instructed to detect and follow the frequency pattern and to press the response key as soon as the deviant frequency pattern was detected (e.g., BBAA). Thus, the task was the same in all conditions, and there was no mention of the duration or intensity feature patterns or deviants. These features were to be ignored. Participants were instructed to focus on the standard frequency feature patterns and frequency deviants.

Participants sat in a comfortable chair in an electrically shielded and sound-controlled booth (IAC, Bronx, NY). The session started with a practice of the frequency deviant pattern detection task. One run of the FA condition was presented for practice, although this run was not repeated for the recording session. Four different randomized stimulus blocks of 720 tones (180 patterns) were presented in each of the three conditions. The FA condition was recorded first to obtain a baseline measure. The FD and FI conditions were then counterbalanced across participants. Half of the participants completed the FD condition first and the other half completed the FI condition first. A 10-min break was provided at the midpoint, and participants were disconnected from the recording system. Total session time, including electrode placement and breaks, was 2.5 h.

EEG Recordings and Data Reduction

EEG was recorded using a 32-channel electrode cap (Electro-Cap International Inc., Eaton, OH), using the International modified 10–20 system, including electrodes placed on the left and right mastoids (LM and RM, respectively). The tip of the nose was used for the reference electrode and P09 for the ground electrode. A bipolar configuration was used to monitor the horizontal electrooculogram (EOG), between electrodes F7 and F8, and between FP1 and an external electrode placed below the left eye to monitor the vertical EOG. Impedances were maintained below 5 kOhms. EEG and EOG were digitized at a sampling rate of 500 Hz with a band-pass of 0.05–100 Hz. The EEG was then filtered offline with a

high-pass cutoff of 0.1 Hz and a low-pass cutoff of 30 Hz using a finite impulse response filter with zero phase shift and a roll-off slope of 24 dB/octave. Filtered EEG was then epoched into 600-ms segments, including a 100-ms prestimulus period. Epochs were baseline corrected before artifact rejection was applied with a criterion set at $\pm 75 \mu\text{V}$ on all electrodes (EOG and EEG). On average, 12% of the overall epochs were rejected due to artifact. The remaining EEG epochs were averaged separately by stimulus type, separately for each condition, and then baseline corrected to the prestimulus period. The standard four-tone patterns occurring before and after the deviant four-tone patterns were excluded from averaging to avoid potential overlap of standards and deviants in the grand averages.

The first tone of the standard pattern and the first tone of the deviant pattern were used to create the standard and deviant waveforms, respectively. This is because the pattern could be detected as deviant (as a violation of the pattern), from the first tone of the pattern.

The MMN component was delineated in the grand-mean difference waveforms (deviant minus standard), and the peak of the MMN was first visually identified in the grand-mean difference waveform, in each condition, at the mastoid electrodes where the inversion was observed. The mastoid was used to determine where to statistically measure the MMN because when a task is performed there is overlap of the MMN with the N2b components, observed at the frontal electrodes. As there is no polarity inversion at the mastoid for the N2b component, the inversion at the mastoid was used to delineate the peak of the MMN in all conditions, and for all stimulus types (task-relevant and task-irrelevant). To statistically evaluate the presence of the MMN component, a 50-ms window (centered on the peak latency of the MMN obtained from the LM in the grand-mean ERP difference waveforms) was used to obtain the mean amplitudes for the standard and deviant ERPs in each individual separately, and in each condition. The P3b component was also delineated in the grand-mean difference waveforms, and the peak latency was visually identified from the Pz electrode, where the signal-to-noise (S/N) ratio is greatest. Using a similar procedure as for the MMN, a 60-ms window centered on the grand-mean peak was used to obtain mean amplitudes in the standard and deviant waveforms for each individual, for each stimulus type, in each condition.

Peak latencies observed in the difference waveforms were used to determine the intervals to calculate the mean component amplitude as follows: 174 ms for MMNs elicited by the frequency pattern deviant in all conditions, 214 ms for the MMN elicited by the duration pattern deviant in the FD condition, and 198 ms for the MMN elicited by the intensity pattern deviant in the FI condition. Peak latency of 382 ms was used for the P3b elicited by the frequency pattern deviant in all conditions, and 428 ms was used to test for P3b in the duration pattern deviant in the FD condition. There was no observable P3b peak elicited by the intensity pattern deviant in the FI condition, thus 378 ms was used as the peak latency, where the largest positive amplitude was determined in the difference waveforms using a peak detection program (Neuroscan, Compumedics). Latency measures were obtained for each individual using a peak detection program calculated on the corresponding electrode of maximal S/N ratio (LM for MMN and Pz for P3b components) and the interval used to calculate the amplitudes.

To statistically verify the presence of the MMN and P3b, as well as the typical scalp topography of the components, one-sample (two-tailed) t tests were calculated (against zero) at relevant electrodes (Fz, Cz, Pz, LM) for each component, in each condition, separately. Due to the overlap of the attention-related components (e.g., N2b) at the frontal electrodes, MMNs were statistically verified as present at the mastoid electrode (LM). The P3b component was statistically verified as present at the Pz electrode, the scalp location of its maximal amplitude in young adults. To assess effects of condition or deviant pattern type on MMN, one-way analyses of variance (ANOVAs) were separately calculated for amplitude and latency.

Hit rate (HR), false alarm rate (FAR), and reaction time (RT) were calculated for the deviant frequency pattern detection in each condition separately. Button presses were considered correct if they occurred between 100–900 ms from tone onset of the frequency pattern reversal. Separate one-way repeated measures ANOVAs were calculated to compare HR, FAR, and RT across conditions.

Where data violated the assumption of sphericity, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Corrected p values are reported. For post hoc analyses, when the omnibus ANOVA was significant, Tukey's HSD for repeated measures was conducted on pairwise contrasts. Contrasts were reported as significantly different at $p < .05$. All statistical analyses were performed using Statistica 12 software (Statsoft, Inc., Tulsa, OK).

Results

Behavioral Results

Table 1 summarizes the mean behavioral performance for the frequency pattern deviants in each condition. There was an effect of condition on RT, $F(1.56, 15.56) = 23.03$, $p < .001$, $\eta_p^2 = .70$, and HR, $F(1.57, 15.71) = 8.20$, $p = .006$, $\eta_p^2 = .45$. Post hoc tests showed that RT was shorter in the FA condition (482 ms) than the FD (581 ms) and FI (585 ms) conditions, with no difference between FD and FI. Post hoc tests also revealed that HR was significantly higher in the FA condition (.92) than either the FD (.70) or FI (.78) conditions, with no significant difference between FD and FI. There was a main effect of condition on FAR, $F(1.3, 13.1) = 5.65$, $p = .027$, $\eta_p^2 = .36$. Post hoc calculations showed significantly greater false alarms in the FD condition (.16) than the FA (.004) condition, but with no significant difference between FI (.09) and FA conditions, or between the FD and FI conditions. FAR was almost exclusively due to button presses to the pattern deviants of the task-irrelevant features (.155/.158 and .088/.091, Table 1).

ERP Results

Tables 2 and 3 present the mean amplitudes for the MMN and P3b components, respectively, evoked by the average of the deviant patterns, standard patterns, along with the differences (deviant minus standard) at the midline (Fz, Cz, and Pz) electrodes, and also at LM for MMN. These data are visually presented in Figures 2 and 3. Figure 2 displays the ERP responses evoked by the standard and deviant feature patterns for each condition. Figure 3

displays the deviant-minus-standard difference waveforms for the Fz, Pz, and LM electrodes for all conditions and stimulus types, and maps of the scalp voltage distribution of the MMN and P3b components at their respective peak latencies.

MMN amplitude—Significant MMNs were elicited by task-relevant frequency pattern deviants in the FA, FD, and FI conditions, with frontocentral scalp distribution and inversion of polarity at the mastoid electrodes, typical of MMN topography (Table 2, Figure 3). Significant MMNs were also elicited by task-irrelevant duration patterns (FD condition) and intensity patterns (FI condition). Table 2 summarizes the mean amplitudes, standard deviations, and significance values for all stimulus types and conditions.

Figure 3 displays the deviant-minus-standard difference waveforms for the Fz, Pz, and LM electrodes for all conditions and stimulus types. The Fz mean difference elicited by the task-specific frequency patterns (FA, FD, FI) were of similar amplitudes (no main effect of condition, $F(1.76,17.58) = 2.52, p = .11$). The LM mean difference amplitudes of all the MMNs (task-relevant and task-irrelevant) were compared across deviant types (frequency, duration, and intensity patterns) and were also not significantly different from each other (no main effect of deviant type, $F(2.77,27.68) = 1.24, p = .31$).

MMN latency—Peak latency of the MMN was calculated by the mastoid electrode due to overlap at the midline electrodes with attention-related processes. A one-way repeated measures ANOVA on the latency at LM revealed a significant main effect of deviant type, $F(2.63,26.32) = 27.92, p < .001, \eta_p^2 = .74$. Post hoc analysis revealed that there were no significant differences in the mean peak latency of the task-specific frequency pattern MMNs, FA: 164 ms ($SD = 15$); FD: 179 ms ($SD = 21$); FI: 170 ms ($SD = 20$). Post hoc calculations also showed that the mean peak latency of the duration MMN (225 ms, $SD = 17$) was significantly longer than the mean peak latency of the frequency MMNs and intensity MMN (200 ms, $SD = 19$). This longer MMN mean peak latency for duration was simply due to the fact that the 50-ms delay before tone duration could be detected as deviant (in contrast to tone frequency deviants that could be detected from tone onset). The peak latency of the frequency MMNs were also significantly shorter than the intensity MMN.

P3b amplitude—Significant P3b components were elicited by all task-specific frequency pattern deviants, with maximal amplitude at the Pz electrode consistent with typical P3b scalp topography (Table 3). P3b components were not elicited by either of the task-irrelevant pattern deviants in the FD and FI conditions. Table 3 summarizes the mean amplitudes, standard deviations, and significance values for all stimulus types and conditions.

The comparison of the mean P3b component amplitude elicited by the task-relevant target frequency deviants revealed a main effect of condition, $F(1.31,13.1) = 6.37, p = .019, \eta_p^2 = .39$. Post hoc calculation showed that the mean P3b amplitude elicited in the FA condition (11.95 μV) was significantly larger than that elicited in the FD (8.65 μV) and FI (8.28 μV) conditions, with no difference between FD and FI conditions.

P3b latency—Condition had no significant effect on mean peak P3b latency for the target frequency pattern deviants, FA: 391 ms ($SD = 18$); FD: 387 ms ($SD = 21$); FI: 395 ms ($SD = 17$) (no main effect of condition: $F(1.63, 16.28) < 1$, $p = .52$).

Discussion

The current study tested processing of simultaneously occurring sequential tone feature patterns when attention was directed to perform a task with one of them. Behavioral and electrophysiological measures were used to assess task-relevant and task-irrelevant sound processing to address the question of whether tone feature patterns were held in memory as organized separate informational streams even when they were irrelevant to task performance. We found evidence for multiple task performance, in both task-relevant and task-irrelevant informational streams, a type of multitasking that decreased behavioral performance.

The task was easier when there were no distracting feature patterns. Participants performed significantly better when the frequency feature pattern occurred alone (in the FA condition) than when there was a competing, task-irrelevant feature pattern (in the FD and FI conditions, respectively). This was demonstrated by a higher hit rate, shorter reaction time, and a lower false alarm rate to frequency pattern reversals in the FA condition. Notably, the error rate was due almost entirely to button presses to the irrelevant feature patterns (duration and intensity), suggesting that the task-irrelevant feature patterns interfered with the ability to perform the task. Thus, this result indicates that the irrelevant feature patterns were processed on some level even though they were not targets. It is possible for this study that the patterns interfered with the task because the competing information (in the irrelevant feature streams) was similar to the target task. That is, the irrelevant information may have interfered because feature patterns occurred in all stimulus dimensions. This then may have set up a type of go/no-go strategy in which determination of task relevancy of the detected pattern deviants was first established, and then followed by a button press. Thus, interference may have been due to pattern tracking among the feature streams.

Another index of pattern tracking was the MMN component. The MMN was significantly elicited by both task-relevant and task-irrelevant tone feature pattern deviants. Because pattern deviance detection is dependent upon the standard pattern being held in memory, MMN elicitation by task-irrelevant deviants indicated ongoing monitoring of all streams of information. Thus, the MMN results are consistent with background monitoring of informational sound streams. However, the MMN amplitude did not reflect behavioral response accuracy (and neither did MMN latency). Whereas response accuracy was significantly higher in the FA condition than the FD and FI conditions, similarly sized MMN amplitudes were elicited by all frequency pattern targets (i.e., no effect of condition on MMN amplitude). This would be expected considering that elicitation of the MMN component is largely attention independent; that is, it reflects deviance detection but not attentional load factors (Sussman, 2007).

The P3b component, on the other hand, is attention dependent, and does reflect attentional factors. Frequency targets in all three conditions significantly elicited the P3b component,

demonstrating that targets were accurately identified in all conditions. The shorter RT was not reflected by the peak latency of the P3b component. However, the P3b amplitude did reflect response accuracy (i.e., HR). The amplitude of the P3b elicited in the FA condition was significantly larger than that elicited by targets (frequency pattern reversals) in the FD and FI conditions. This is consistent with the behavioral finding of a significantly higher HR to targets in the FA condition than in the FD and FI conditions. The significantly reduced amplitude of the P3b in the FD and FI conditions may reflect a difference in cognitive load across conditions necessitated by filtering out distracting events; P3b amplitude can reflect cognitive load differences associated with target detection (Squires, Donchin, Herning, & McCarthy, 1977). Alternatively, it is possible that, in the presence of additional feature patterns, a portion of attention was allocated to monitoring the irrelevant sounds in the event of task relevancy or to rule them out. Thus, the reduced amplitude may reflect a level of processing allocated to the competing task-irrelevant tone feature patterns, if the strategy for performing the task included all or some divided attention among the deviant feature patterns in deciding when to press the button. This latter interpretation is suggested by the nearly significant P3b elicited for the task-irrelevant duration deviant in the FD condition, and by the error analysis, in which 98% of the FAR in the FD condition was due to erroneous button presses to the task-irrelevant duration pattern deviants, and in the FI condition, 97% of the erroneous button presses were to task-irrelevant intensity pattern deviants.

According to load theory, perceptual load is a crucial factor influencing distractor processing (Lavie, 2005). Distractor interference occurs only under low perceptual load conditions. Therefore, in the current paradigm, behavioral performance should have been the same across all of the conditions because perceptual load was not increased. The task was the same in all conditions. However, our results demonstrated a level of processing of the distractor stimuli when there were competing stimuli, which was indexed by reduced HR, reduced amplitude P3b, and elicitation of MMN. Thus, our results are more consistent with Konstantinou, Beal, King, and Lavie (2014) who found that, when processing load was increased in working memory (dissociated from perceptual load), distractors did interfere with task processing. The MMN results of the current study provide new evidence to suggest that interference may have occurred due to working memory processing being automatically loaded by pattern processing. Together with behavioral effects, these findings show that working memory processes interact with selective attention (Pasternak & Greenlee, 2005).

The memory-load demands induced by processing patterns in background sounds negatively influenced task performance. This suggests a kind of multitasking situation that includes both relevant and irrelevant information. Although the overall benefit of this type of multitasking for the auditory system would be greater flexibility, where streams of information could be maintained in memory and available in the background in case of the need to attend to them, there was a negative consequence. The quality of task performance was lowered by competing stimuli that required some level of processing (perhaps higher than MMN because MMN was unaffected by performance). This suggests that there are limitations in the ability to multitask. The implication of these results is that the most effective way to accomplish tasks is one at a time, and perhaps supports the idea that we can only do one task at a time with high proficiency. In the current case, when processing

simultaneously occurring distinct feature patterns that share memory resources, more mistakes were made. Our data therefore are consistent with the notion that what appears to be multitasking is more likely divided attention, such that when one task requires full attention, it is at a detriment to other tasks.

Acknowledgments

This research was supported by funds from the National Institute of Deafness and Other Communication Disorders (DC004263, ESS), the Yeshiva University Undergraduate Summer Research Scholars Program, and the Summer Undergraduate Research Program (SURP) of the Albert Einstein College of Medicine.

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Figure 1.

Stimulus paradigm. Timing is depicted on the abscissa (in ms) and frequency (in Hz) on the ordinate. Tones presented every 250 ms are denoted with filled, colored rectangles. The start of the four-tone standard frequency pattern and the four-tone standard duration and intensity patterns are staggered so they do not coincide on the same tones. A: Frequency alone (FA) condition. Black solid rectangles represent the standard four-tone feature pattern. Low frequency was presented at 1046 Hz and higher frequency at 1175 Hz (low-low-high-high). The pattern reversal (deviant) is depicted with orange solid rectangles (high-high-low-low), in all conditions. Standard and deviant feature patterns are delineated with a dashed rectangle. B: Frequency-duration (FD) condition. Tone duration is depicted by shorter and longer rectangles. The standard duration four-tone pattern was presented with 150-ms (long) and 50-ms (short) duration tones (long-long-short-short). The duration pattern deviant is denoted by the solid blue rectangles (short-short-long-long). The dashed rectangles highlight the standard and deviant patterns. C: Frequency-intensity (FI) condition. Frequency pattern

standards and deviants are delineated with dashed rectangles. Tone intensity is depicted by shading, with the black and dark orange rectangles denoting 70 dB peak SPL (louder) sounds and gray and lighter orange rectangles denoting 60 dB peak SPL (softer) sounds. The standard intensity four-tone pattern was presented in the pattern of loud-loud-soft-soft, and the intensity pattern deviant as soft-soft-loud-loud.

Figure 2.

ERPs. Grand-mean waveform evoked by the deviant (thick, solid black line) and standard (thin, solid black line) from a frontal electrode (Fz) and for the deviant from a parietal electrode (Pz, dashed black line), separately for the frequency alone condition (top), the frequency-duration condition (middle), and the frequency-intensity condition (bottom). Responses to the task-relevant frequency patterns are shown (left), responses to the task-irrelevant patterns (right). The dotted line at zero is stimulus onset. The abscissa depicts time (in ms) and the ordinate depicts amplitude (μV).

Figure 3.

Difference waveforms. Grand-mean deviant-minus-standard difference waveforms are displayed for the Fz electrode (thick solid line), Pz electrode (thin solid line), and the left mastoid (LM, dashed green line) for task-relevant (left) and task-irrelevant (right) pattern reversals, for the frequency-alone (top), frequency-duration (middle), and frequency-intensity (bottom) conditions. Dashed rectangles outline the significantly elicited MMN and P3b components. Maps of the scalp voltage distribution are displayed for the MMN and P3b components at their respective peak latencies (see text for details). The scale for the MMN

voltage is .10 $\mu\text{V}/\text{step}$ and for the P3b is .20 $\mu\text{V}/\text{step}$, with blue denoting negative polarity and red denoting positive polarity.

Table 1

Behavioral Results

Condition	Hit rate	Overall FAR	Task-irrelevant FAR	Reaction time
Frequency alone	.92 (.05)	.004 (.005)	–	482 (75)
Frequency duration	.70 (.23)	.158 (.179)	.155 (.178)	581 (76)
Frequency intensity	.78 (.17)	.091 (.079)	.088 (.079)	585 (77)

Note. Standard deviation in parentheses; reaction time in ms.

FAR = false alarm rate.

Table 2

MMN Results

Condition		Stimulus type					
FA	Frequency						
	Electrode	Dev	Std	Diff			
	Fz	-3.03 (2.4)	0.95 (0.99)	-3.98***			
	Cz	-2.00 (2.76)	1.17 (1.04)	-3.17**			
	Pz	0.48 (1.92)	0.23 (0.80)	0.25			
	LM	1.21 (1.26)	-0.64 (0.42)	1.85***			
FD	Duration						
	Electrode	Dev	Std	Diff			
	Fz	-1.97 (1.80)	0.83 (1.15)	-2.80**	-2.24 (1.24)	-0.03 (0.92)	-2.21***
	Cz	-1.15 (1.97)	0.87 (1.40)	-2.02*	-1.25 (1.39)	0.08 (1.32)	-1.33 [†]
	Pz	0.46 (1.53)	0.10 (1.30)	0.36	0.17 (1.09)	0.08 (1.35)	0.09
	LM	1.62 (1.42)	-0.04 (0.87)	1.66***	1.27 (1.04)	-0.41 (0.53)	1.68***
FI	Intensity						
	Electrode	Dev	Std	Diff			
	Fz	-3.03 (2.01)	0.59 (1.15)	-3.62***	-0.04 (1.57)	0.32 (0.98)	-0.36
	Cz	-2.87 (2.78)	0.42 (0.97)	-3.29**	0.00 (1.64)	0.34 (1.08)	-0.34
	Pz	-1.36 (1.73)	-0.01 (0.61)	-1.37*	0.51 (1.56)	-0.01 (1.20)	0.52
	LM	1.02 (1.44)	-0.11 (0.53)	1.13*	0.78 (0.59)	-0.26 (0.74)	1.04**

Note. Amplitudes in μV ; standard deviation in parentheses.
Conditions: FA = frequency alone; FD = frequency duration; FI = frequency intensity; Dev = deviant; Std = standard; Diff = difference.
One-sample t tests (against zero) significance levels:
[†] $p < .10$.

.100' > *p*

'10' .*p*
**
'500 > *p*
*

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Table 3

P3b Results

Condition		Stimulus type					
FA	Electrode	Frequency			Diff		
		Dev	Std	Diff			
	Fz	3.94 (5.06)	0.48 (1.65)	3.46 [‡]			
	Cz	7.94 (8.00)	0.31 (1.88)	7.63 [*]			
	Pz	11.67 (8.47)	-0.28 (1.30)	11.95 ^{**}			
FD	Electrode	Frequency			Duration		
		Dev	Std	Diff	Dev	Std	Diff
	Fz	2.53 (4.20)	0.22 (0.77)	2.31	-0.49 (2.62)	-0.09 (1.19)	-0.40
	Cz	5.57 (7.69)	0.07 (0.94)	5.50 [*]	1.57 (4.27)	-0.31 (1.32)	1.89
	Pz	8.64 (9.94)	-0.02 (1.09)	8.65 [*]	2.99 (5.94)	-0.11 (1.42)	3.10 [‡]
FI	Electrode	Frequency			Intensity		
		Dev	Std	Diff	Dev	Std	Diff
	Fz	1.85 (3.56)	0.38 (1.32)	1.47	-0.08 (2.24)	-0.34 (1.70)	0.26
	Cz	5.42 (6.79)	0.25 (1.18)	5.16 [*]	-0.16 (2.70)	-0.70 (1.95)	0.55
	Pz	8.46 (9.29)	0.18 (0.76)	8.28 [*]	0.04 (2.25)	-0.81 (1.94)	0.86

Note. Amplitudes in μV ; standard deviation in parentheses.

Conditions: FA = frequency alone; FD = frequency duration; FI = frequency intensity; Dev = deviant; Std = standard; Diff = difference.

One-sample t tests (against zero) significance levels:

- [‡] $p < .10$,
- ^{*} $p < .05$,
- ^{**} $p < .01$,
- ^{***} $p < .001$.